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APPLICATION OF RESISTIVITY METHOD FOR MOISTURE ESTIMATION IN TOP SOIL LAYER

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1985-86

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ABSTRACT

Use of resistivity method is well established in ground water exploration. Studies of unsaturated zone are important because they can provide information about soil moisture content in the subsurface. Soil moisture measurements play vital role for studies in the field of hydrology, meteorology and agriculture etc. The occurrence of soil water in the root zone is important for optimum crop production. Conventional instruments for resistivity surveys are quite common and are already available. Though the nuclear techniques such as neutron probe are better suited for soil moisture studies, however, the costs and risks involved may somewhat limit their use for field studies on a wider scale. For general field use, resistivity techniques could provide a versatile approach, if, their applicability in soil moisture estimation could be established. The report also discusses various conventional and geophysical (including nuclear) methods, and their usefulness in soil moisture studies.

Electrical properties of water such as conductivity and dielectric constant which form basis of a number of electrical and electronic moisture meters are defined. Resistivity investigations were carried out using Megger at the Campus of National Institute of Hydrology, Roorkee. Electrode separation of 0.25 - 2.5 meter was taken in electrical soundings with Wenner Configuration. Soil moisture measurements were taken by Neutron moisture probe. An attempt was made to study the effect of climatic conditions on moisture and resistivity of the soil layers and to develop a strategy for employing electrical methods for estimating soil moisture.

Results obtained during the course of these investigations indicate that the electrical methods could be used for estimation of soil moisture. Soil moisture measurements carried out using neutron probe and electrical

resistivity meter have also been correlated. These investigations indicate an inverse relationship between soil moisture content and corresponding soil resistivity observations. However, further studies on these lines on a comprehensive basis would be necessary, for arriving at definite conclusions.

1.0 INTRODUCTION

The moisture content in the unsaturated zone is of importance. Recent studies have indicated that measurement of soil moisture content is important not only in the field of agriculture for planning irrigation regimes, yield estimation and erosion forecasting; but also in the field of hydrology for infiltration and drainage studies, groundwater recharge measurements and water balance studies. The moisture content of the surface layers is important for partitioning of rainfall into runoff and infiltration components. The soil layer considered is that which can interact with the atmosphere through evapotranspiration i.e. the soil root zone and the moisture content of this layer fluctuates in response to precipitation, irrigation and potential evapotranspiration. Various classical meothods have been in use in the past for estimating soil moisture. Geophysical investigations are also effectively utilized in various hydrological applications, however ,they have not yet made place for soil moisture studies. Among the geophysical methods, the electrical methods are considered feasible for soil moisture studies. Therefore, it is proposed to attempt surface resistivity technique for rapid estimation of soil moisture in conjunction with nuclear techniques.

Physio-chemical properties like temperature, salinity, dielectric constant etc. of water besides the properties of soil affect resistivity/conductivity of soils. The electric properties of wet soils are dependent primarily on the amount of moisture. The conductivity of intrinsic water is 0.0548×10^{-6} mho per cm at $25^{\circ}C$ estimated theoretically. Water is a dipolar as well as a typical associated liquid.When an electric voltage is applied,it shows conduction due to presence of $[H^+]$and$[OH^-]$ions.The conductivity of a substance is the reciprocal of its volume resistivity,which is the longitudinal resistance per unit of length of a uniform cylinder of the substance of the unit cross sectional area. While employing electrical methods for moisture measurement, it is normal practice to use terms resistance (R) more often than conductivity. This is because most electrical instruments operate on the relationship between moisture content and the specific resistance of soil between two fixed points. Specific resistance is usually defined as the resistance between the opposite faces of a one cm cube of the material.

The high dielectric constant of water is well known. No other liquid approaches it in this property. The value of the dielectric constant of water, expressed in electrostatic units, can be defined as the ratio of the mutual electrical capacity of a given pair of equipotential surfaces, fixed with reference to each other, when immersed in the dielectric (water) to their capacity and also when immersed in vaccum.

It has been observed that there is a definite relationship between the moisture content of substances and their dc conductivity or dc resistance. Kujirai and Akhari (1923) studied the change of resistance of some material with changing humidity conditions and found that resistance fell with increasing humidity, the logarithm of the resistance being practically a linear function of the moisture content. They also studied the effect of the duration of application of the voltage and found that resistance-rise was gradual and it continued to rise for 5 minute after the current was switched on. Whereas if the relative humidity was below 30%, the resistance was not dependent on the time factor. Murphy and Walker (1928) obtained similar results. They showed that the logarithm of longitudinal resistance varied linearly with moisture content.

Hasselbatt (1928) and Stamn (1928) found that the logarithm of the resistance is approximately proportional to the percentage of moisture content below the saturation level. At a given moisture content the ordinary resistance law governing solid conductors i.e. $R \propto (\frac{L}{A})$ where R, L, and A are resistance, length and area of the conductor respectively, appears to hold approximately for many hygroscopic materials.

Various geophysical methods and their applicoations are being describedin following sections. The use of resistivity technique is found suitable for soil moisture studies in the unsaturated zone and have been applied for carrying out soil moisture studies in the campus of National Institute of Hydrology, Roorkee. Attempt has been made to develop a strategy for employing these methods in field conditions successfully. Soil moisture studies using resistivity method is not as rapid as nuclear techniques such as neutron probe, however it could provide a simple technique for field application with use of easily available instruments.

1.1 Electrical Resistivity Method

Geophysical exploration involves the determination of subsurface structure by means of surface physical measurements. Surface geophysical methods are based on measurements of anomalies in physical forces at the earth's surface which must be interpreted in terms of subsurface geology. Although geophysical measurements are in general more expensive than geological and hydrological methods, they are preferred where geological structures and bodies are not exposed. Surface geophysical methods are difficult to interpret, but they have been proved useful for locating and analyzing groundwater. Success in applying these methods depends on the existence of sufficient contrasts in the physical properties such as electrical conductivity, elasticity, density, magnetic susceptibility etc. in subsurface formations.

An essential characteristic for applying any geophysical method is the variation and continuity of physical properties. In the electrical resistivity methods, the distinctness of surface indications depends upon the contrasts in the physical properties of subsurface formations. In the resistivity method, used for determining depths of horizontal formations, these physical properties must remain uniform in a horizontal direction since the spacing of transmitting and receiving units is changed horizontally to obtain increased depth penetration.

The resistivity of rocks and formations varies widely with the material and its porosity, grain packing, water content and conductivity/resistivity. Resistivity of igneous and metamorphic rocks may range from $10\text{-}10^7$ ohm-m, whereas those of unconsolidated formations may vary from $1\text{-}10^3$ ohm-m. Heiland (1946) presented an extensive tabulation of the resistivities of elements, minerals, ores, rocks, consolidated sediments, unconsolidated formations, oil and water. In general, the resistivity of a formation can be expressed by

$$\rho = \frac{c}{\rho} \rho_w \qquad \ldots(1)$$

in which ρ = resistivity of the rock or formation,

ρ_w = resistivity of the water filling the voids

α = porosity and

c = constant depending on the arrangement of the void space in the formation.

If it is assumed that groundwater fills all of the voids, resistivity can be expressed by (Heiland, 1946).

$$\rho = \frac{3 - \alpha}{2\alpha} \rho_w \qquad \ldots(2)$$

The electrical resistivity method is applicable to depth determinations of horizontal formations and the mapping of dipping strata. This method depends on the measurement of the potential difference between two points due to current in the primary circuit. The ratio of potential difference and current, multiplied by a factor that depends on the arrangement of the electrodes, gives the resistivity of the ground. That is true resistivity only if the medium of is homogeneous . If layers of different conductivities are present, it represents an apparent resistivity. Apparent resistivity is commonly calculated by the same formula that applies to homogenous ground. Consider an electric current 'I' entering a homogeneous and isotropic ground of resistivity " ρ " by means of two electrodes C_1 and C_2 (Fig.1a). If the current flows from C_1 and C_2, the potential 'V' at any point P is

$$V_P = \frac{\rho I}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \qquad \ldots(3)$$

Similarly, the potential difference between two points P_1 and P_2 (Fig.1b) is

$$V_{P1} - V_{P2} = V = \frac{\rho I}{\pi} \left(\frac{1}{r1} - \frac{1}{r2} - \frac{1}{r3} + \frac{1}{r4} \right) \qquad \ldots(4)$$

Thus the resistivity is

$$\rho = \frac{2\pi V}{I} \left(\frac{1}{\left(\frac{1}{r1} - \frac{1}{r2} - \frac{1}{r3} + \frac{1}{r4} \right)} \right) \qquad \ldots(5)$$

equation (5) holds for any position of the electrodes C_1, C_2, P_1 and P_2. Various electrode spacing arrangements have been used in practice. The most common arrangements are Wenner (Fig.1C) and Schlumberger arrangement (Fig.1d). In the Wenner arrangement, the potential electrodes are placed on a line with the current electrodes, so that all electro-

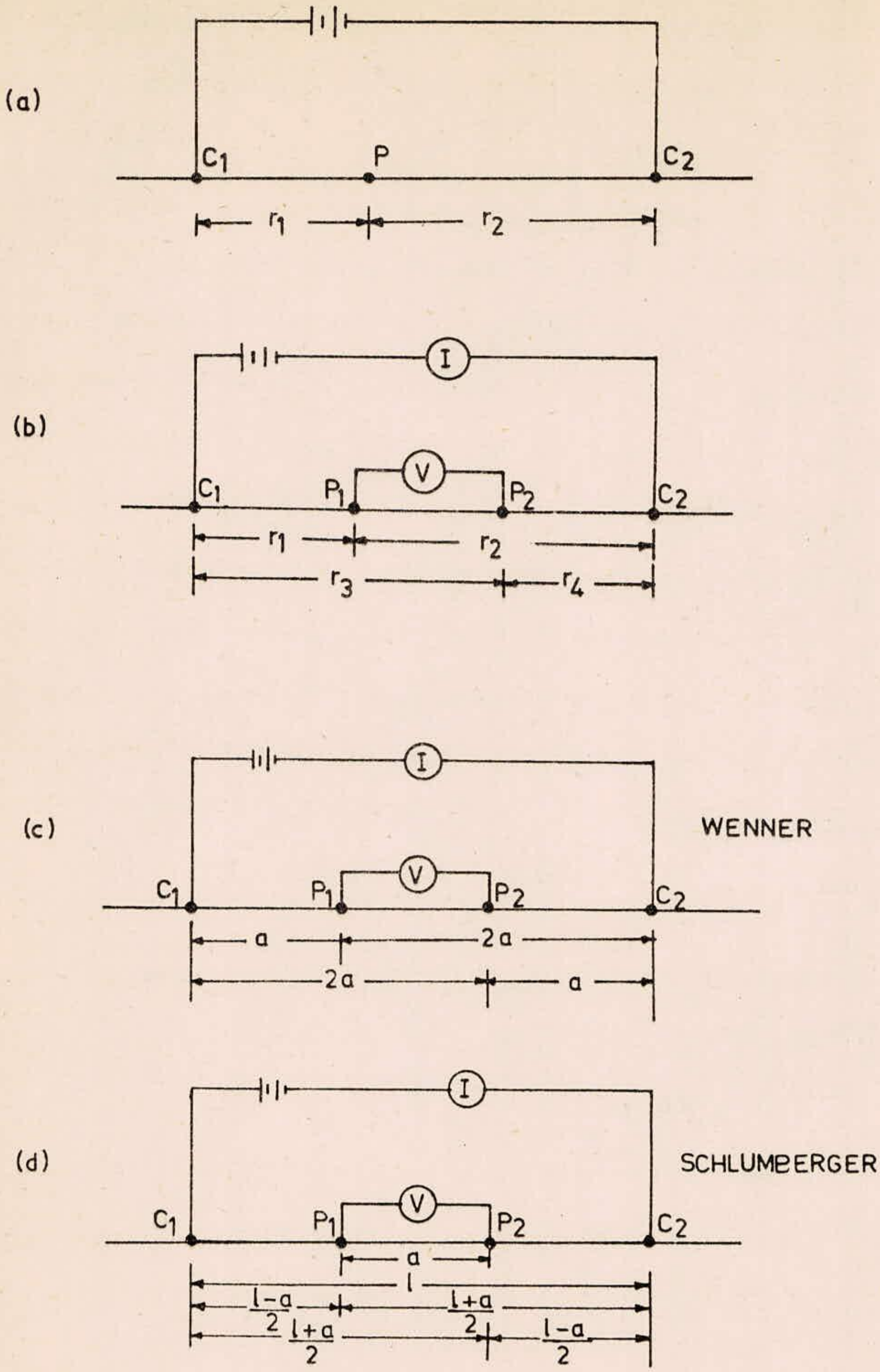


FIG. 1. SCHEMATIC REPRESENTATION OF ELECTRODE ARRANGEMENT

des are equidistant from one another. If 'a' is the distance between the electrodes, $r_1 = r_4 = a$ and $r_2 = r_3 = 2a$. Then from equation (5) the resistivity is

$$\rho = \frac{2\pi aV}{I} \qquad \ldots(6)$$

In the Schlumberger arrangement, the potential electrodes are close together. If 'l' is the distance between the current electrodes and 'a' the potential electrode seperation $r_1 = r_4 = \frac{l-a}{2}$; $r2 = r3 = \frac{l+a}{2}$

and the resistivity

$$\rho = \frac{\pi V}{aI}\left[(l/2)^2 - (a/2)^2\right] \qquad \ldots(7)$$

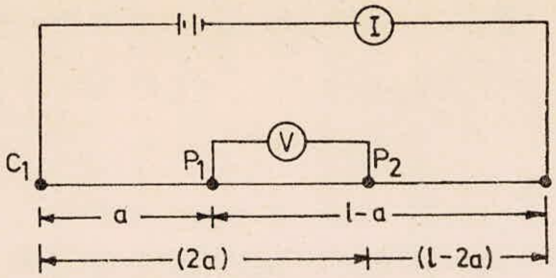
In the asymmetrical double electrode arrangement, shown in fig.2a, the potential electrodes are situated at equal intervals from one current electrode but asymmetrical with respect to the center. With $r_1 = a$, $r_2 = l-a$, $r_3 = 2a$, and $r_4 = l-2a$, the resistivity is

$$\rho = \frac{2\pi V}{I} , \frac{2a(l-a)(l-2a)}{(l-2a)^2 + al} \qquad \ldots(8)$$

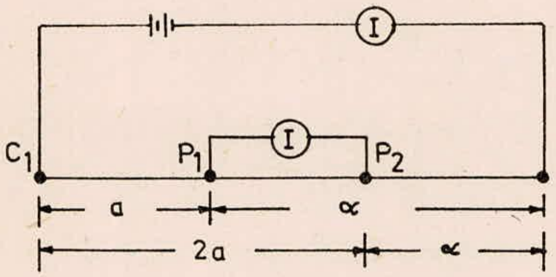
In the double equidistant electrode arrangement (Fig.2b), the potential electrodes are placed at equal intervals from one current electrode whereas the second current electrode is far removed. With $r_1 = a$, $r_2 = r_4 = \infty$ and $r_3 = 2a$, the resistivity is

$$\rho = \frac{4\pi aV}{I} \qquad \ldots(9)$$

The resistivity method can be applied in two ways. In the first, the electrode spacing is kept constant (i.e.constant depth penetration) and the arrangement as a whole is moved over the ground. This procedure is called resistivity mapping or electrical trenching. In the second



a. ASYMMETRICAL DOUBLE ELECTRODE ARRANGEMENT



b. DOUBLE EQUIDISTANT ELECTRODE ARRANGEMENT FOR THE MEASUREMENT OF EARTH RESISTIVITY

FIG. 2.- DOUBLE ELECTRODE ARRANGEMENT FOR MEASURING EARTH S RESISTIVITY

way, measurements are made at one location(the center of the measuring arrangement) from which the spacing of the electrodes is gradually increased to pick up changes in resistivity with depth. In this manner, the depth penetration is increased and the apparent resistivity is obtained as a function of depth. This procedure is called resistivity sounding or electrical drilling. It is used for determining depths of horizontal boundaries such as the water table and interfaces of stratified formations. The apparent resistivity measured by this procedure is affected by the entire depth of penetration. Thus, the greater the number of layers penetrated, the more difficult it is to interpret the resistivity sounding.

Interpretation of resistivity data may be done qualitatively or quantitatively. Qualitative interpretation, based on the appearance of the curves, is used mainly in resistivity mapping, with a decline in apparent resistivity indicating the approach of formations of better conductivity, and vice-versa. Quantitative interpretation is primarily based on use of type curves. The type curve method involves the construction of field (data) and theoretical (type) curves. Interpretation comprises of placing the field curves over the type curves and determining the depth by interpolation. The type curves are constructed for given conductivity ratios and for various layer thickness or depths. The data curves have apparent resistivities plotted as ordinates, and the electrode seperations plotted as abscissas. This method of depth determination is applicable mainly to two and three layer conditions (Zohdy et.al.1974). The electrical resistivity method has been widely used for groundwater investigations. Its greatest success has been with two layer problems (Gay and Kosten, 1956; Kelly, 1962), particularly in locating subsurface fresh and salt-water boundaries (Swartz, 1937, 1939, 1940). The resistivity method is limited to relatively simple geologic structures unless additional information is available from other geophysical methods or from drilling.

1.2 Other Geophysical Methods

Other surface geophysical methods are seismic, gravity and magnetic methods. Seismic methods measure the geological bodies to physical fields. In this method, an explosive is detonated at or near the surface and the clastic impulses or vibrations are picked up by seismometers (also known as detectors or geophones) and recorded on magnetic tape or photographic paper. The time lapse between generation of impulse and detection of the vibrations is referred to as travel time. The fan-shooting method provides the simplest way, of determining the nature or character of the media occuring between the point of explosion (shot point) and a number of detectors. Seismic prospecting may involve refraction or reflection shooting. The basic difference between reflection and refraction techniques is in the location of detectors w.r.t.the shot point. Reflection technique has been widely used in geophysical prospecting for oil but marginally in exploration for groundwater.

Gravity methods are based on measuring any variations in the gravitational field at the earth's surface. Because the gravitational effects of bodies or masses are proporotional to the density differences among themselves and their vicinity. Gravity methods are suitable for locating structures in stratified formations. Usually, reconnaissance gravity surveys are relatively rapid and inexpensive but give only regional information. This method has been widely used in prospecting for oil and has very little application to ground water exploration. Under ideal circumstances, gravity variation might be used successfully in determining the depths of thick alluvial deposits bordering a mountain area or the locations of intrusive bodies constituting an aquifer boundary (Todd, 1959).

Magnetic methods are based on the measurement of small variations in the earth's magnetic field. In this class of methods, measurements are made of anomalies in the earth's magnetic field and result from geologic bodies that differ from each other in degrees of magnetism. As in gravity methods and in contrast to electrical and seismic methods, magnetic prospecting utilizes a natural field of force. Measurements of anomalies in the earth's magnetic field are probably the simplest, least expensive and fastest of all geophysical methods (Heiland, 1946). Natural magnetic anomalies are ordinarily related to geologic bodies at great depth or to local variations which are seldom related to groundwater occurrence. Groundwater studies can derive some assistance from magnetic exploration when water occurs in troughs underlain by crystalline or igneous rocks or when water movement is blocked by faults or dikes.

1.3 Subsurface Geophysical Methods

Subsurface geophysical methods, also referred to as geophysical logging techniques have been widely used in the petroleum industry. Several of the techniques have been used in connection with the location and construction of water wells. Well logging signifies any operation in which some characteristic data of the formations penetrated by a drill hole are recorded as a function of depth. Geologic logs furnish valuable information on the location of water bearing zones. Geophysical logging consists of spontaneous potential logging, resistivity logging, radioactivity logging, sonic logging, temperature logging and various other logging techniques. Fluid-velocity and fluid-resistivity surveys are perhaps most useful in groundwater investigation.

2.0 REVIEW

Methods of moisture measurements can be broadly classified into two groups: direct(chemical) and indirect(physical) methods. In direct methods, moisture is normally removed from the material by oven drying, desiccation, distillation, and other physiochemical techniques, and its quantity found by weighing or by observing changes in the pressure or temperature. Techniques based on these principles, which are usually employed in the laboratory, have a high degree of accuracy and in most cases with proper precautions in sampling can be made to yield absolute values. In indirect methods, moisture is not removed from the material, but parameters of the wet soil which depend on the quantity of water or number of constitutent hydrogen atoms present are measured instead.

These two categories of techniques have their own advantages and disadvantages. It is possible to get very accurate and even absolute values by employing one or more direct methods. The time required for these methods, however, is usually considerable and operations are mostly manual. Indirect methods, though dependent in accuracy on the results of direct measurements against which they are calibirated, are quicker than direct methods. Further, only the indirect methods offer the possibility of continuous measurement of moisture content. Once a particular instrument has been calibirated at a certain setting, very little attention and time is required to measure the moisture content. The increase in instrumentation has been one of the striking advances over the past decade and today the determinaotion of moisture is more often achieved by instrumental methods than by direct analysis. There has been tremendous development in methods for estimating moisture content through the application of modern physical techniques such as neutron scattering, electrical and electronic methods etc.

2.1 Gravimetric Method

Gravimetric method for measuring soil moisture is the oldest but most widely used method for obtaining data on soil moisture. Becasue it is the only direct way of measuring soil moisture, it is required for calibrating the equipment used in the other methods. It involves collecting a soil sample, weighing the sample before and after drying it and calculating its moisture content. Russel (1950) and Whitney (1929) described some of the first scientific investigations for soil moisture measurement using gravimetric methods. Many types of sampling equipment as well as special drying ovens and balances have been developed for use with the gravimetric method. Van Bavel and Gilbert (1954) have discussed a method for approximating the water content of soils.

The conventional method is to dry the soil in an oven at 105°C till constant weight is obtained. The moisture content is expressed as a percentage of the oven dry weight. The disadvantage of the gravimetric method is the time and effort required to obtain data. It is time consuming to collect the samples, especially from depths greater than a few meter, and to oven dry and weigh the large number of samples.

2.2 Electrical Resistance Method

Among the many types of instruments proposed and developed for rapid and reliable soil moisture measurement, the most promising are those which involve measurement of electric resistance in a porous material that is in moisture equilibrium with the solid soil enclosing it. The principle of electrical measurement of soil moisture was first reported by Whitney (1929). However, many years passed before successful electrical units were developed by Bouyoucos and Mick (1947), Colman (1946), Youker and Dreibelbis (1951), Korty and Kohnke (1953) and Colman and Hendrix (1949). A number of instruments based on the principle of the resistance variation in accordance with the change in moisture content have been developed. The most important of these are the ones developed by Colman and Hendrix (1949) and Bouyoucos and Mick (1947). For most accurate deter mination of soil moisture the resistance meters need calibration for each soil and temperature correction for each measurement.

2.2.2 Capacitance or Dielectric Method

The procedure for obtaining the electrical capacity is similar to that of determining the electrical resistance. For measurement of capacitance, a wheatstone bridge is used which is balanced with respect to both capacity and resistance. Anderson (1943) determined the relationship between electrical capacity and moisture contents of a series of soil samples extending in their range of moisture contents from a moisture equivalent of 6.7 to 29.1%. An electronic moisture meter based on the dielectric variation of moisture content has been developed by Pande (1961). A special needle-type electrode system for measurement of moisture content of soils has also been designed and constructed. The reading of the meter is calibrated to read moisture content values directly, no graph or charts are required. A good agreement between the results obtained by this technique and those obtained by oven drying method was found. This electrode system and meter can be conveniently used for irrigation purposes in agricultural fields (Pande 1965).

The capacitance method of measurement of soil moisture content is a very promising method whereby it would seem unnecessary to calibrate the condenser over the entire range of soil moisture content for every soil on which the method is used. With decrease of soil moisture content, the electrical capacity of the block begins to drop from a rather high value to a little above the permanent wilting percentage of the soil.

2.3 Geophysical Methods

Among the geophyscial methods, the electrical method are found suitable for hydrological studies because of low-expenses involved, faster coverage and wider range of applicability. The theory and interpretation of this method is well developed for their reliable application. The physio-chemical properties e.g.temperature, salinity etc. of water besides the properties of soil effect resistivity of soils. The electrical properties of wet soils are dependent primarily on the amount of moisture, its salinity and distribution in the pore spaces. Saturated soils have lower resistivity than unsaturated and dry ones. The presence of clays and conductive material also reduces the resistivity of the soil (Zohdy et.al1980). There are various geophysical methods including natural field methods, including telluric current, magnetotelluric, spontaneous polarization and streaming potential methods. Zohdy et.al.(1980) used the Magneto-telluric method to measure earth resistivity. Magneto-telluric measurements at several frequencies provide information on the variation of resistivity with depth because the depth of penetration of E.M. waves is a function of frequency. The main advantages of this method are estimation of true resistivity of the layers and greater depth resolution. Spontaneous polarization or streaming potential method have been more successfully used in search of minerals than water. In ground water investigation, potentials generated by water moving through a porous media are measured. Measurements of these potentials have been used to locate leaks in reservoirs and canals. Koerner, et.al.(1979) have described use of this method in detecting location of subsurface water and seepage and presented a comprehensive review of the methods available for detecting subsurface water and seepage.

Besides examples described above, the most widely employed application of resistivity method is in groundwater exploration which were reported by various workers and have been reviewed by Goyal et.al(1986). Electromagnetic techniques have been used effectively in mapping burried channels, soil moisture studies etc. by Hockstra (1978). In applying electromagnetic waves for soil moisture studies, three important properties viz. conductivity, permitivity and permeability are important for describing the interaction of electromagnetic waves with soil.

Till recently, seismic methods have been economically used in oil exploration. With application of micro computers for seismic data processing (Hunter et.al., 1984, 1986), use of reflection method for regular hydrological applications has started. Recent ground water investigations have shown that with modern, portable and digital seismic reflection equipment, aquifers several meters thick at depths of several hundred meters can be resolved (Whiteley, 1985). Brief review on use of seismic methods for subsurface seepage detection have been given by Koerner et.al.(1979). The neutron scattering method of measuring soil water content is founded upon the physical principles concerning the interaction between neutrons and the medium. The neutron was discovered in 1931 but its specific application to the detection of moisture in soil was described 20 years later by Belcher et.al (1950). Since then an increasing number of reports and papers have been published and various forms of commercial instruments are now available to make routine measurements of the moisture content of soils.

Nuclear techniques have, in the past twenty years, made significant contributions to studies on surface and subsurface hydrology. For soil moisture studies, nuclear techniques are found very much suitable. The theory of Neutron scattering method and its instrumentation have been discussed by Ramesh Chand (1986).

Ramesh Chand et.al(1986) elaborated the technique of soil moisture measurement and the interpretation of data, obtained at the campus of National Institute of Hydrology, Roorkee using Troxler depth moisture gauge. Other applications of nuclear techniques for hydrological investigation are reviewed by Ramesh Chand and Seth (1986). In brief, Isotope techniques provide the potential for investigation of changes in soil moisture content in the unsaturated zone besides various other application for hydrological studies.

2.4 Other Methods of Measuring Moisture Content

Various other methods which include hygrometric method, microwave method, thermal conductivity method, hydrophotographic method and tensiometric method have also been widely used for soil moisture studies. A large number of investigators have studied the relationship between relative humidity of air and moisture content of soil. Labedeff (1952) was one of the first to determine relative humidity of soil/air. He found it by means of the hair hygrometer. Puri(1949) determined the relation between soil moisture and relative humidity of the soil/air by keeping soil at a particular humidity in a closed container or by passing air of particular humidity through the soil for a long time. Fukuda (1956) used an electric hygrometer to determine the relative humidity in soil pores and concluded that relative humidity below 100% depends mainly on soil moisture rather than temperature. A method for the insitu determination of moisture content based on the relationship between the relative humidity and the moisture content of porous materials has been developed by De Costro (1965).

Microwave moisture meter has several advantages over existing equipment and methods of moisture measurement. Because of the low attenuation of most basic dry materials, the meters measure only the water in a sample and nothing else. Further, no contact with the sample is necessary and so the method is non destructive and does not cause contamination. The thermal conductivity method is based on the relation between moisture content and thermal conductivity of materials. If this relation is known, the moisture content can be estimated from the thermal conductivity data. Kazo (1971) applied this method for the determination of moisture content. By employing this method it is also possible to determine the moisture distribution which is otherwise difficult to estimate by other conventional methods. Heat diffusion through the moist soil has also sometimes been used to measure its moisture content. This method is based on the principle that heat conductivity of a soil varies with its moisture content.

Hygrophotographic method consists of placing a relative emulsion layer of silver and mercury iodide in contact with the soil, which absorbs the humidity at a speed which increases with the rise in moisture content of the soil, and which records the latter by a change in coloring proportionate to the amount of moisture absorbed. This method gives measurement of moisture content present even in the minutest quantities and is specially suited for the determination of soil moisture following a protracted drought. This method has been employed by Sivadjian (1957) for studying the effects of drought on the soil moisture and on the natural vegetation by recording and noting moisture at a depth of 30 cm. or so. This method is claimed to be highly sensitive and accurate. Sivadjian (1957) has also given a large number of pertinent references and compared this method with other well known techniques.

The tensiometer is probably the easiest to install and the most rapidly read of all soil moisture measuring equipment. Tension meters were probably most fully developed by Richards (1963). They are most useful for measuring the moisture content of tensions below approximately 0.9 atm. Such tensions will, on the average, correspond to a range in moisture content from slightly below field capacity to saturation. At the higher tensions found in drier soils, tensiometers become inoperative because air enters the system, through the porous point. Richards (1963) developed multiple tensiometers for determining tension data at several depths by using single probe. Recent studies by the hydrological laboratory of the U.S.Geological Survey (Denver, Colorado) have shown that semi-permeable plastic points provide much faster indication than ceramic points. Allyn and Work (1941) developed a instrument where estimation of soil moisture content is related to the force required to push an instrument through the soil. Equipment for measuring penetration resistance have also been developed.

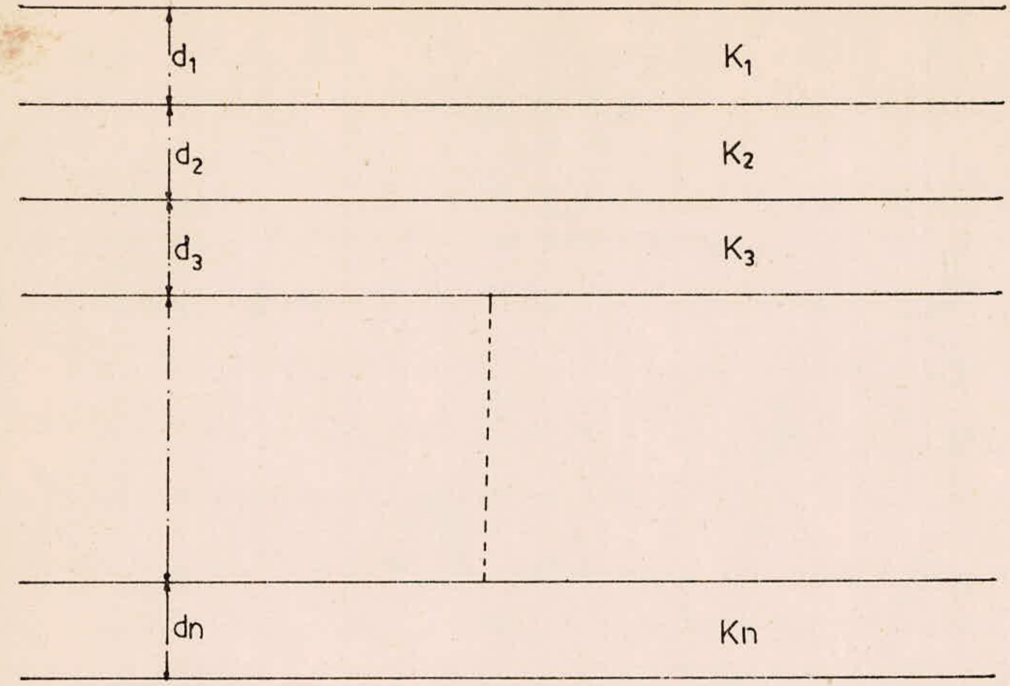
Recently Kazo (1971) has developed and perfected a method for soil moisture determination on the basis of suction force with a tensiometer.

3.0 PROBLEM DEFINITION

In agriculture, horticulture, hydrology and civil engineering etc., the moisture content of soils and clay minerals play a very important role. The physio chemical properties of the various structures and materials utilized in these branches of science are in a large measure dependent on the moisture content as well as the distribution of moisture in them. It is, therefore, natural that a large number of methods and techniques have been developed and applied for estimating the moisture content of soils. Moisture in soils is present in different forms and it is extremely difficult to establish accurate boundaries between these different varieties of soil moisture. Moisture within the earth mass is neither uniformly distributed nor is in static equilibrium. The closer a given point of an earth mass is to the surface, more is the influence of atmospheric factors, such as changes in temperature, airpressure etc. on the soil moisture content. At greater depths, soil moisture is more stable and uniformly distributed through the earth mass than at shallow depths.

Physio-chemical, including thermal properties e.g. temperature, salinity etc. of water besides the properties of soil affect resistivity (reciprocal of conductivity) of soils. The electrical properties of wet soils are dependent primarily on the amount of moisture, its salinity and distribution in the pore spaces. Saturated soils have lower resistivity than unsaturated and dry ones. The higher the porosity of the saturated soils, the lower its resistivity and higher the salinity of of the saturating fluids, the lower the resistivity. The temporal and spatial variation in resistivity is measured at a site and calibration procedure formulated for predicting soil moisture content on the basis of resistivity measurements.

A large number of methods and technique have been developed for the measurement of moisture content of soils, viz.gravimetric method, electrical resistance method, capacitance or dielectric method, hygrometric method, microwave method, neutron scattering method, tensiometric method, hygrophotographic method and thermal conductivity method etc. and are briefly described in section 2.0 of this report. However, nuclear methods and resistivity method have been specially applied for the measurement of moisture content of soils and are discussed.



Taking a series of soil layers of thickness d_1, d_2, d_3......d_n and hydraulic conductivity k_1, k_2, k_3,.....k_n, the velocity flux through each layer is v_1, v_2, v_3.....v_n,. By the mass conservation principle and by Darcy's law .

$$V = \frac{k_1 i_1}{d_1} = \frac{k_2 i_2}{d_2} = \frac{k_3 i_3}{d_3} = \ldots\ldots = \frac{k}{d} \qquad \ldots(10)$$

where i is hydraulic gradient or driving force or causing the water to flow

or

$$V\left(\frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \ldots\ldots \frac{d_n}{k_n}\right) = i_1 + i_2 + i_3 + \ldots + i_n \qquad \ldots(11)$$

or

$$V = \frac{(d_1 + d_2 + d_3 + \ldots. d_n)}{\left(\frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \frac{d_n}{k_n}\right)} \cdot \frac{\Delta H}{(d_1 + d_2 + d_3 + \ldots d_n)} \qquad \ldots(12)$$

4.0 METHODOLOGY

4.1 Moisture Movement in Layered Soils

Water enters the soil in a manner similar to a piston entering a cylinder. Almost all the air and water in the pores is displaced by the entering water. The soil solution is displaced and is replaced by the added water. Actually it is difficult to completely remove all of the air from a soil. Saturated soil is only about 90% of total saturation. The flow of fluids through the individual pores of a porous media is very complex. Furtunately, an empirical law discovered by Henry Darcy in 1856 adequately describes the flow through a large mass of soil. Darcy's law states that the flow of water through porous material is proportional to the hydraulic gradient and to a factor 'k' which is a characteristics of the particular porous media. The hydraulic gradient represents the driving force that causes the water to move. K is hydraulic conductivity and varies with depth in the soil. The variation may be due to natural soil development or to stratification in alluvial deposits. Each soil layer has a different hydraulic conductivity. The average vertical hydraulic conductivity is calculated by applying Darcy's law to the flow through each individual layer. Since no water is gained or lost in passing through the various layers, the principle of conservation of mass may be used to calculate an average vertical hydraulic conductivity.

Let us consider a layered case, where d_1, d_2, $d_3 \ldots . d_n$ are the thickness of soil layers. and k_1, k_2, $k_3 \ldots . k_n$, the Hydraulic conductivities of individual layers.

Now the weighted harmonic mean vertical hydraulic conductivity is given by

$$k_y = \frac{d_1 + d_2 + d_3 + \ldots\ldots + d_n}{\left(\frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} \ldots\ldots + \frac{d_n}{k_n}\right)} \qquad \ldots(13)$$

$$= \sum_{n=1}^{n} dn \Big/ \frac{dn}{kn} \qquad \ldots(14)$$

Equation (14) represents vertical flow through a stratified column of soil. Considering horizontal flow through a stratified soil, the flow through each layer will be

$$Q_1 = k_1 \, i_1 \, d_1$$

$$Q_2 = k_2 \, i_2 \, d_2$$

$$Q_3 = k_3 \, i_3 \, d_3$$

$$Q_n = k_n \, i_n \, d_n$$

The total flow, Q will be the sum of the flow through the individual layers

$$Q = Q_1 + Q_2 + Q_3 + \ldots\ldots + Q_n$$

$$= (k_1 \, d_1 + k_2 \, d_2 + \ldots\ldots k_n \, d_n)i \qquad \ldots(16)$$

The velocity flux through the soil will be

$$V_H = \frac{Q}{A} = \frac{(k_1 \, d_1 + k_2 \, d_2 + k_3 \, d_3 + \ldots\ldots k_n d_n)i}{d_1 + d_2 + d_3 + \ldots\ldots\ldots + d_n} \qquad \ldots(17)$$

The average horizontal hydraulic conductivity will be

$$K_x = \sum_{n=1}^{n} k_n \, d_n / d_n \qquad \ldots(18)$$

Within each layer, the soil may be homogenous. The horizontal conductivity is same as the vertical conductivity within any particular layer. However, when the entire soil mass is considered then the effect of this layering of the soil results in an average horizontal conductivity that is always greater than the average vertical conductivity.

If the hydraulic conductivity and thickness of each layer is known, the pressure head at the interfaces between the layers can be calculated. The velocity flux through the column (V) may be calculated as

$$V = k_y\, i \ldots \qquad \ldots(19)$$

If H_1 is the hydraulic head at the top of the soil column and H_2 is the unknown hydraulic head at the top layer and the interface between the second layer, then

$$V = k_y\, i = k_1 \frac{H_1 - H_2}{d_1}$$

or

$$H_2 = H_1 - V \frac{d_1}{k_1} \qquad \ldots(20)$$

and

$$H_2 = \frac{P_2}{\gamma} + Z_2 \qquad \ldots(21)$$

where γ = specific weight of fluid ($= \rho g$)

P_2 = Pressure in fluid

Z_2 = vertical distance from a reference plane

equation (21) may be rewritten s

$$\frac{P_2}{\gamma} = H_2 - Z_2$$

where the reference plane for hydraulic head coincides with the bottom of the column. The soil hydraulic conductivity ($k=\frac{v}{i}$) has the dimensions are used for rainfall intensity or irrigation application rates. The simple expression of Darcy's law in terms of hydraulic conductivity does not include the effect of viscosity or density of the fluid. Since flow through porous media is inversely proportional to the viscosity, Darcy's law can be written as $V = \frac{k' \rho g}{\mu}\, i$

where K' = intrinsic permeability. Thus $K = \frac{v}{i} = \frac{k' \rho g}{\mu}$ ...(22)

and k may be measured in the laboratory by collecting undisturbed soil core samples.

4.2 Moisture Movement in Unsaturated Media

The flow of water through unsatûrated media follows Darcy's Law. The main difference through saturated and unsaturated flow is the hydraulic conductivity. For saturated flow the hydraulic conductivity is constant regardless of the pressure. For unsaturated flow the hydraulic conductivity is a function of the negative pore pressure. Since soil moisture content is a funcotion of the pore pressure, one can say that the unsaturated hydraulic conductivity is also a function of the moisture content. As the pore pressure becomes more negative, the larger soil pores are drained and no longer conduct the water. The water now moves through the smaller pores which have reduced conductivity. The soil pore pressure and the soil moisture content are related to each other by the moisture characteristics curve. Unsaturated flow is sometimes called capillary flow. The moisture regime above a water table is subject to unsaturated flow. The infiltration process where by rain or irrigation water penetrates into the soil is generally unsaturated flow.

The entry of water into soil is termed as infiltration. The process of infiltration is important in recharging groundwater, irrigation and hydrology. There are two forces acting on water causing it to enter the soil. Gravity acts in a downward direction. Capillary forces also act on the water. If the soil is initially dry, the capillary forces are much greater than the gravity force. The water moves downward into the soil in a manner similar to a piston moving down in the cylinder. The wetted soil behind the wetting front is called the transmission zone. As the wetting front advances into the soil, the transmission zone lengthens. Since the pressure head behind the wetting front is relatively constant, the pressure gradient across the transmission zone decreases causing the infiltration rate to decrease with time.

4.3 Field Investigations Carried Out

Soil moisture studies were carried out using neutron probe and resistivity measurements were taken by Megger(Earth Tester Model ET 3/2). The surveys were conducted in the Campus of National Institute of Hydrology.

For carrying out moisture measurements, holes were drilled and access tubes, made of aluminium of 41.25 mm outer diameter, were installed. These tubes provided an access to samples at desired depths, protectedthe probe from direct contact with the soil and allowed for repeating the observations. After installing the access tubes in the study area, neutron moisture gauge is placed on the tube. Soil moisture content measurements were taken by lowering the probe into the access tube. The observations were taken upto 2.5 meter depth at 0.10 meter depth intervals from 0.20 m below the surface down to the bottom of the tube. Basic principles of neutron probe, calibration and the installation of access tubes and other relevant information has been given in detail in the technical report No.28 of NIH(Ramesh Chand et.al.1985-86). Some of the findings are also reported separately (Ramesh Chand 1986).

The resistivity of soil layers in NIH. is studied by using megger earth tester resistivity unit (Fig.3) by measuring the electric potential produced at the earth surface by an electric current that

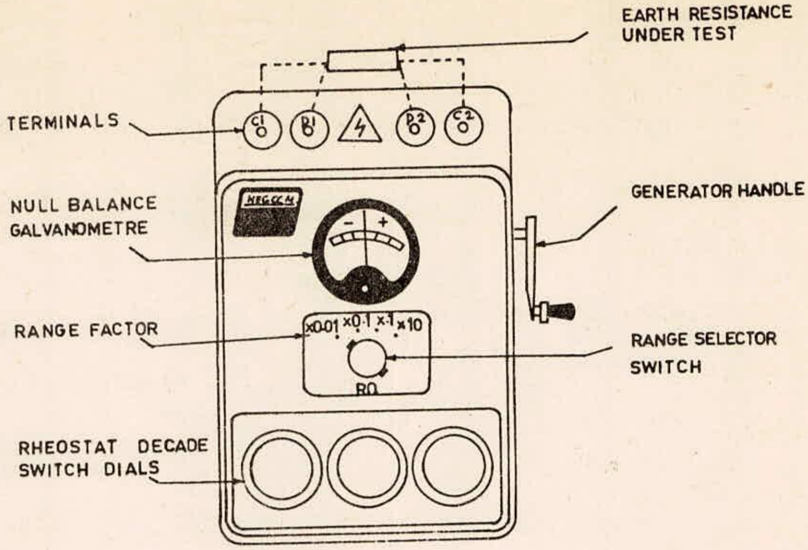


FIG. 3 - FRONT PANEL LAYOUT OF MEGGER EARTH TESTER RESISTIVITY UNIT

is passed through the surface into the field. The electric current has been produced by an a.c.generator for taking resistivity measurements at the NIH Campus. The megger used for survey contains a hand driven a.c.generator. Current is passed between the two current electrodes. The voltage drop across the potential electrodes(Fig.4) is balanced by voltage which is generated from the a.c.output via a current transformer across a digital resistor system. The out of balance current caused by the differece of potentials is rectified and passed to a centre-zero moving coil micro-ammeter. When the meter reads zero, a reading in ohms is taken from the digital switch.

Earth resistance can be measured in four ranges (0.01 ohm to 9.99 ohm; 0.1 ohm to 99.9 ohm; 1ohm to 999 ohm and 10 ohm to 9990 ohm) with an accuracy of ± 1% of range used. The null balance method of reading from a centre-zero moving coil micro-ammeter means that, at the point of balance no current flows through the potential electrodes.

The Wenner electrode configuration shown in Fig.4 uses four equidistant metal electrodes which are driven into ground. Two inner electrodes are used to measure potential difference developed due to passage of current through the outer electrodes. The measured resistance 'R' multiplied by geometric factor, which is a function of inter electrode seperation 'a', gives the apparent soil resistivity to a depth 'a'. The field observation were taken using inter electrode separations in the range of 25-250 cm with increments of 25 cm. Soil moisture measurements were taken simultaneously by using neutron moisture gauge in the units of Kg/Cubic meter, pounds per cubic foot, inches per foot, millimeters per meter and in volume percent. Instrument measure moisture content of soils, aggregates or other similar materials and works on the principle of neutron thermalisation. It

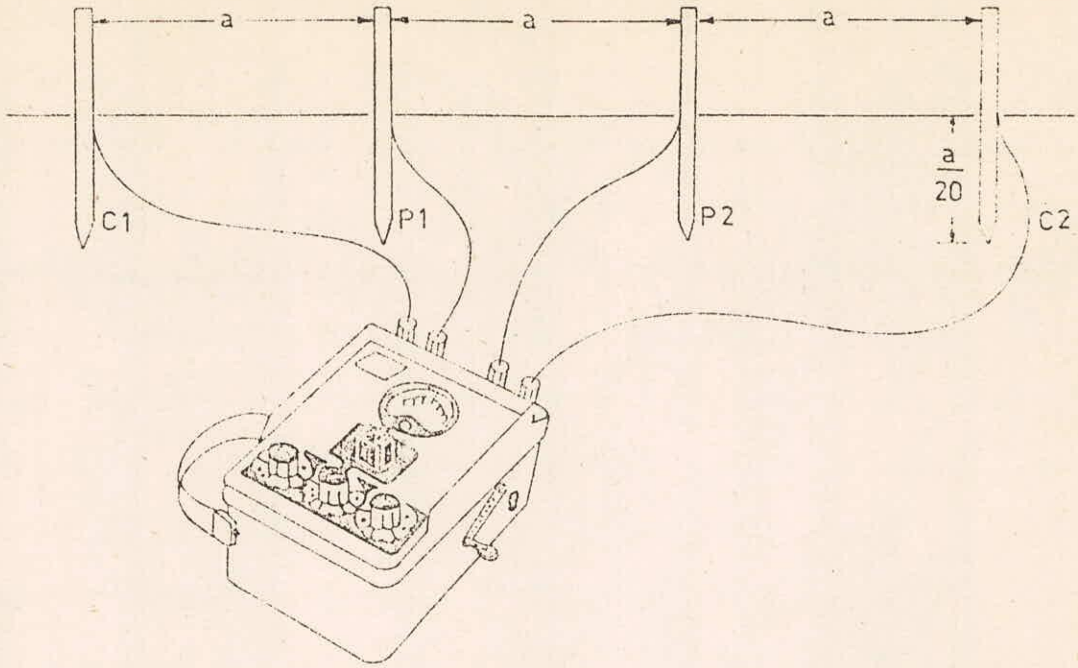


FIG. 4. SET UP FOR MEASURING EARTH RESISTANCE USING MEGGAR IN WENNER ELECTRODE CONFIGURATION

consists of essentially a probe containing a fast neutron source, a slow neutron counter, adjacent to the neutron source. Soil moisture was measured at various depths at the site of observation where resistivity measurements were also carried out.

Resistivity soundings were taken in the month of September, October and December 1985 on 30th Sept., 1st & 3rd October, and 17th, 18th, 20th & 21st December, 1985, for which moisture data was also collected by using neutron moisoture probe. Soil samples were collected in sections of 10cm from each site for seive and grain size analysis. Samples were also subjected for chemical analysis of organic matter in the profile. (Resistivity and soil moisture data is given in Table 1)

The studies were carried out for developing strategies of employing resistivity technique in estimating the soil moisture content in the root zone and not to carry out resistivity survey for exploration of groundwater. The analysis and results are given in later section of the report.

Table I: Resistance and Soil Moisture data

S.No.	Depth (m)	30.9.85 RES	30.9.85 SM	1.10.85 RES	1.10.85 SM	3.10.86 RES	3.10.86 SM	17.12.85 RES	17.12.85 SM	18.12.85 RES	18.12.85 SM	20.12.85 RES	20.12.85 SM	21.12.85 RES	21.12.85 SM
1	.25	47.88	24.5	45.53	26.5	48.83	25.5	102.93	13.3	129.99	12.9	121.52	12.8	129.99	13.0
2	.50	50.87	31.6	49.93	34.8	55.89	34.7	114.59	24.2	125.91	24.0	122.14	24.1	143.81	24.7
3	.75	41.92	39.5	42.85	38.0	48.51	38.0	102.14	36.0	96.55	35.75	100.79	36.0	105.50	36.5
4	1.00	38.31	44.6	36.42	40.4	40.19	41.0	69.58	41.8	70.96	40.1	79.13	40.4	75.99	40.9
5	1.25	32.18	48.0	30.61	42.7	34.54	43.5	56.65	45.9	57.38	44.2	58.87	45.0	59.66	48.6
6	1.50	27.32	49.1	27.32	44.5	30.14	45.4	45.67	50.2	46.34	47.7	48.04	48.3	45.69	49.3
7	1.75	25.28	49.0	24.18	46.2	27.47	47.0	38.90	47.0	40.66	46.5	40.65	48.0	39.67	47.7
8	2.00	22.61	48.4	22.61	47.9	26.38	48.0	36.00	48.0	35.67	47.6	35.77	47.6	35.04	47.7
9	2.25	22.61	46.5	-	-	25.43	44.5	32.60	42.9	32.52	43.0	32.50	44.0	31.79	43.8
10	2.50	21.93	44.8	-	-	25.12	43.5	29.84	44.4	30.77	43.9	29.83	44.3	29.20	44.2

RES = Resistivity in ohms measured by Meggar

SM = Soil moisture percentage measured by Neutron moisture probe

5.0 APPLICATIONS

In ground water studies, the resistivity method can furnish information on subsurface geology, which might be unattainable by other geophysical methods. For example electrical methods are unique in furnishing information concerning the depth of the fresh-salt water interface, whereas neither gravity, magnetic, nor seismic methods can supply such information. A thick clay layer separating two aquifers usually can be detected easily on a sounding curve but the same clay bed may be a low velocity layer in semismic refraction surveys and cause erroneous depth estimates.

Buried stream channels, which can be mapped accurately by the resistivity method, are favoured targets for exploration. Horizontal profiling, electrical soundings or both are used in their mapping, several burried stream channels were discovered in by Zohdy (1964, 1965) and by Page (1968), using the combined techniques of horizontal profiling using the wenner array and electrical sounding using the schlumberger and wenner arrays.

The field application of electrical resistivity to the investigation of the impact of waste disposal of shallow ground water has been documented by several studies (Gilkeson and Cartwright, 1983). Electrical resistivity profiles can be most effectively used when coordinated with test hole data. Electrical resistivity surveys have been used successfully to locate fault zones in potential tunnel alignments (Krynine and Judd, 1957). Electrical soundings and horizontal profiling were made to delineate a fault zone for tapping steam for energy and for delineating geothermal areas(Breusse and Astier, 1961).

There are numerous examples where electrical methods have been applied for ground water surveys, geothermal water potential and for mapping the water table and clay layers. The literature is also rich with case histories of areas in many parts of the world where resistivity method was successfully used for mapping the fresh-salt water interface.

Other geophysical methods are also applied for the study of water resources. Ground water studies have also been made by time domain induced polarization method. Only few induced polarization (IP) surveys have been made for ground water exploration(vacquier and others (1957), Kuzmina and Ogilvi (1965) and Bodmer and others (1968). Seismic refraction measurements have also been applied for ground water studies. However, application of geophysical methods for soil moisture studies has not been established completely and efforts are continuing in this field of study.

6.0 RESULTS

Field investigations were carried out at the Campus of National Institute of Hydrology, Roorkee for establishing the use of surface resistivity technique for measurement of soil moisture content in the unsaturated zone. For this purpose soil moisture measurements were taken by neutron moisture probe and resistivity measurements were taken simultaneously by neutron moisture probe and megger respectively.

Resistivity sounding data were obtained during Sept.-Oct. and Dec. 1985 corresponding to the wet and dry condition, having surface soil moisture values $\geq$ 20% and $\leq$ 15% respectively. Soil moisture measurements were taken at these sounding points. Soil moisture readings taken in the month of September-October and December show the moisture content of the surface layer varying from 24-26% to 12-14% and maximum resistivity values varying from 50-55 ohm metre to 115-145 ohm metre respectively, showing clearly, the variation in resistivity with moisture content. Soil moisture and resistivity data for the corresponding depths are indicated in Table 1.

Apparent resistivity values were plotted against electrode separation (Fig.5) and observed two interfaces at the depth of about 50 cm and 120 cm. Only upto a depth of 50 cm a general increase in resistivity is observed after which resistivity decreases uniformly. Soil moisture data measured is also plotted against resistivity values with depths (Fig.6). Variation in resistivity with soil moisture content is plotted in Fig.7 for different dates. Profile show a unique pattern. The same patter is seen in Fig.8 where resistivity is plotted against total soil water content in the subsurface layers. An inverse trend is observed between the

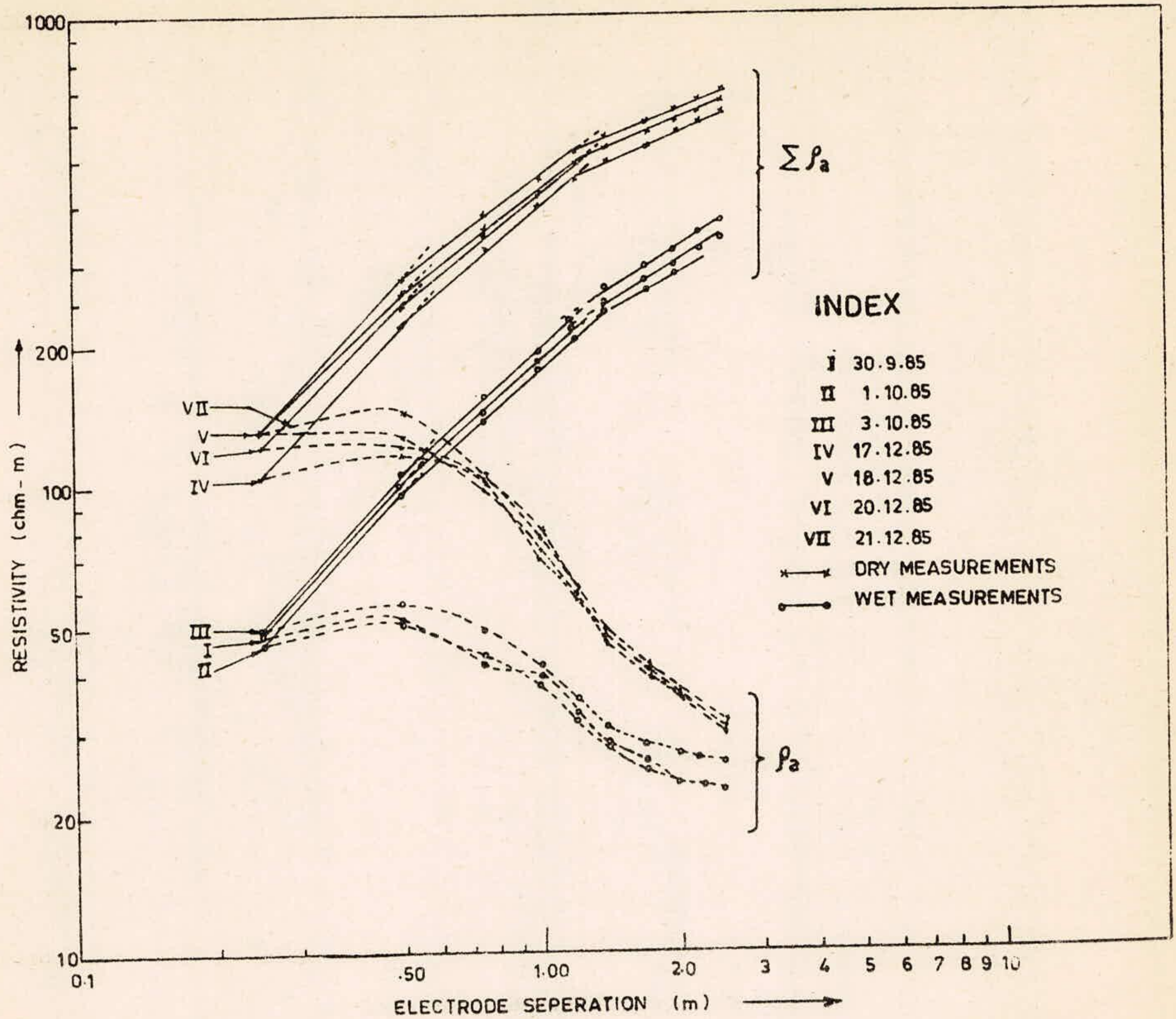


FIG.5 - RESISTIVITY Vs ELECTRODE SEPARATION

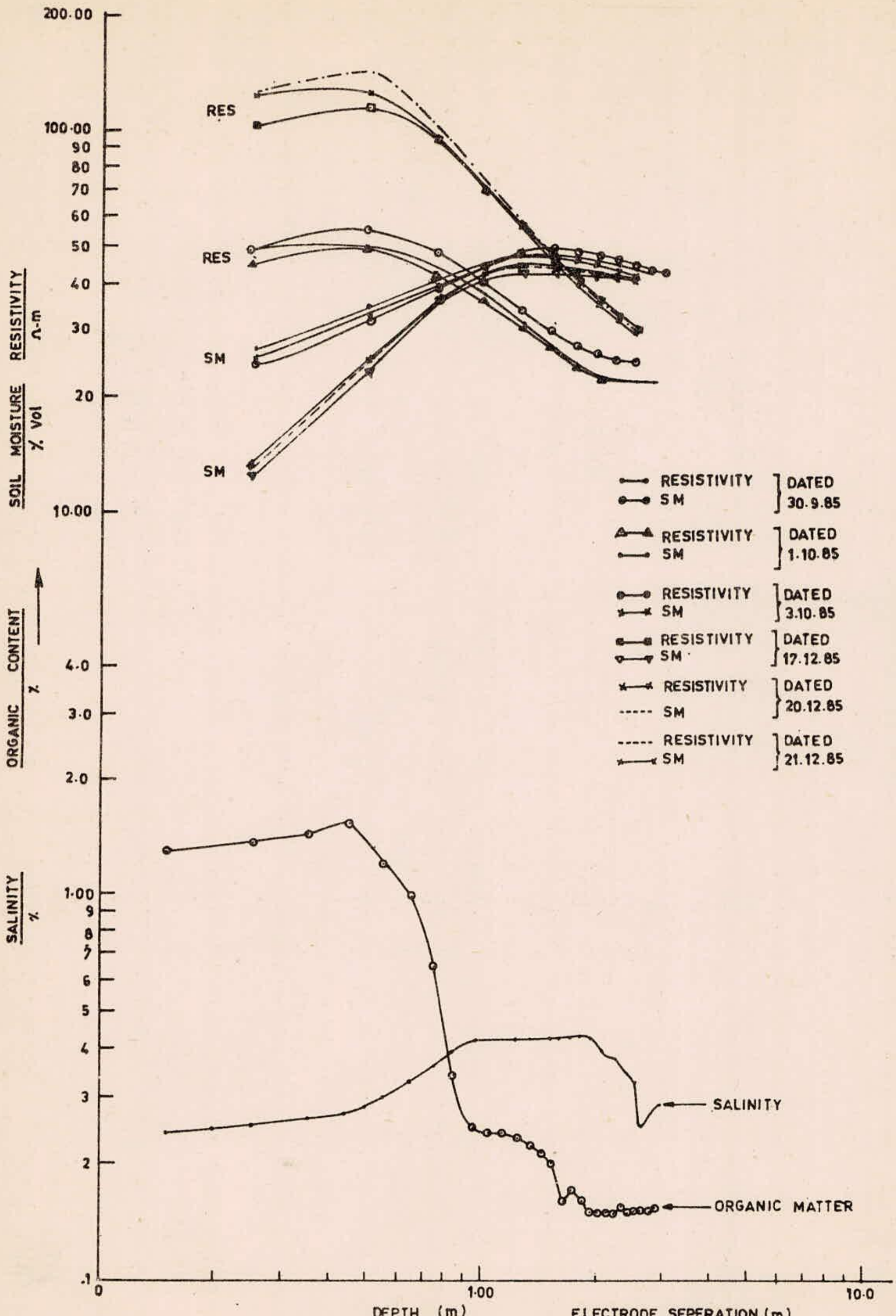


FIG. 6 – SOIL MOISTURE, RESISTIVITY, SALINITY AND ORGANIC CONTENT Vs DEPTH & ELECTRODE SEPARATION.

two. Resistivity is decreasing while soil moisture is increasing.

Soil samples collected at the sounding points were subjected to sieve analysis. A thin band of clay is observed at a depth of 40-50 cm. The initial rise in resistivity is attributed to likely presence of a thin clay band at this depth. The presence of clay lens at this interface increases the resistance of the soil layer and is seen in al the field measurements. Previous studies carried out in the study area showed less variation in moisture content below 120 cm depth (Ramesh Chand, 1986). This is also seen in resistivity data as resistivity curves show less variation at depths below 120 cm.

Use of electrical resistivity method is well established for exploration of ground water resources, however, their use for soil moisture studies has not yet made any place. The application of surface resistivity technique is therefore attempted for soil moisture studies. Resistivity measurements were carried out in the campus of National Institute of Hydrology, Roorkee, using megger. Soil moisture measurements were taken by using neutron moisture probe and thus the effect of dry and wet weather conditions on resistivity and soil moisture was observed and discussed in this report.

The report presents results of preliminary study of soil moisture and resistivity measurements and the variation in resistivity with soil moisture. Resistivity data was interpreted qualitatively to determine any change in soil type or moisture content in the unsaturated zone. Resistivity and soil moisture data depict distinct patterns in wet and dry weather conditions.

Variation in resistivity is negligible for moisture content $\simeq$ 40% while for moisture content lower than 40%, high variation in resistivity is observed. Results obtained show the suitability of electrical

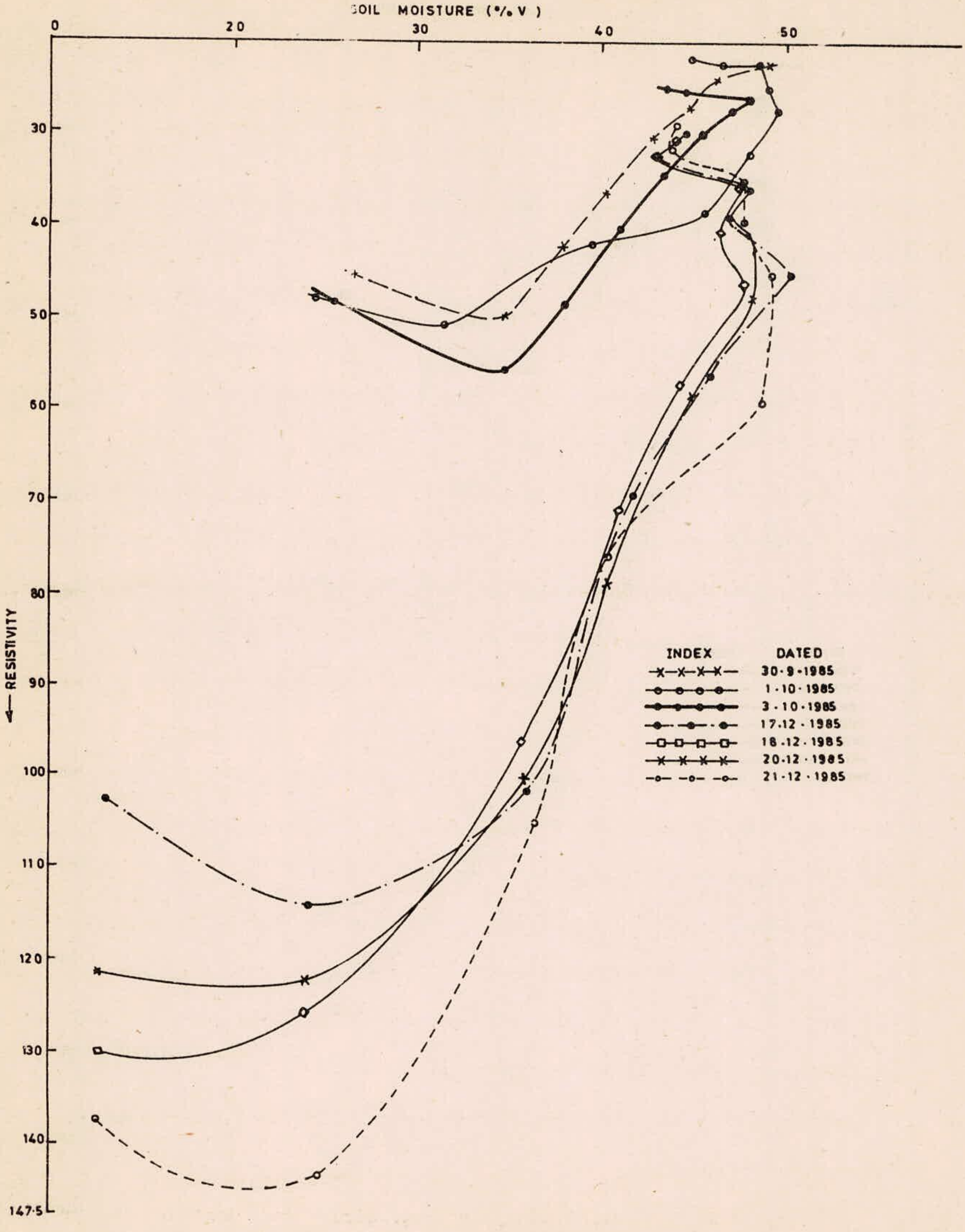


FIG. 7- VARIATION IN RESISTIVITY WITH SOIL MOISTURE CONTENT

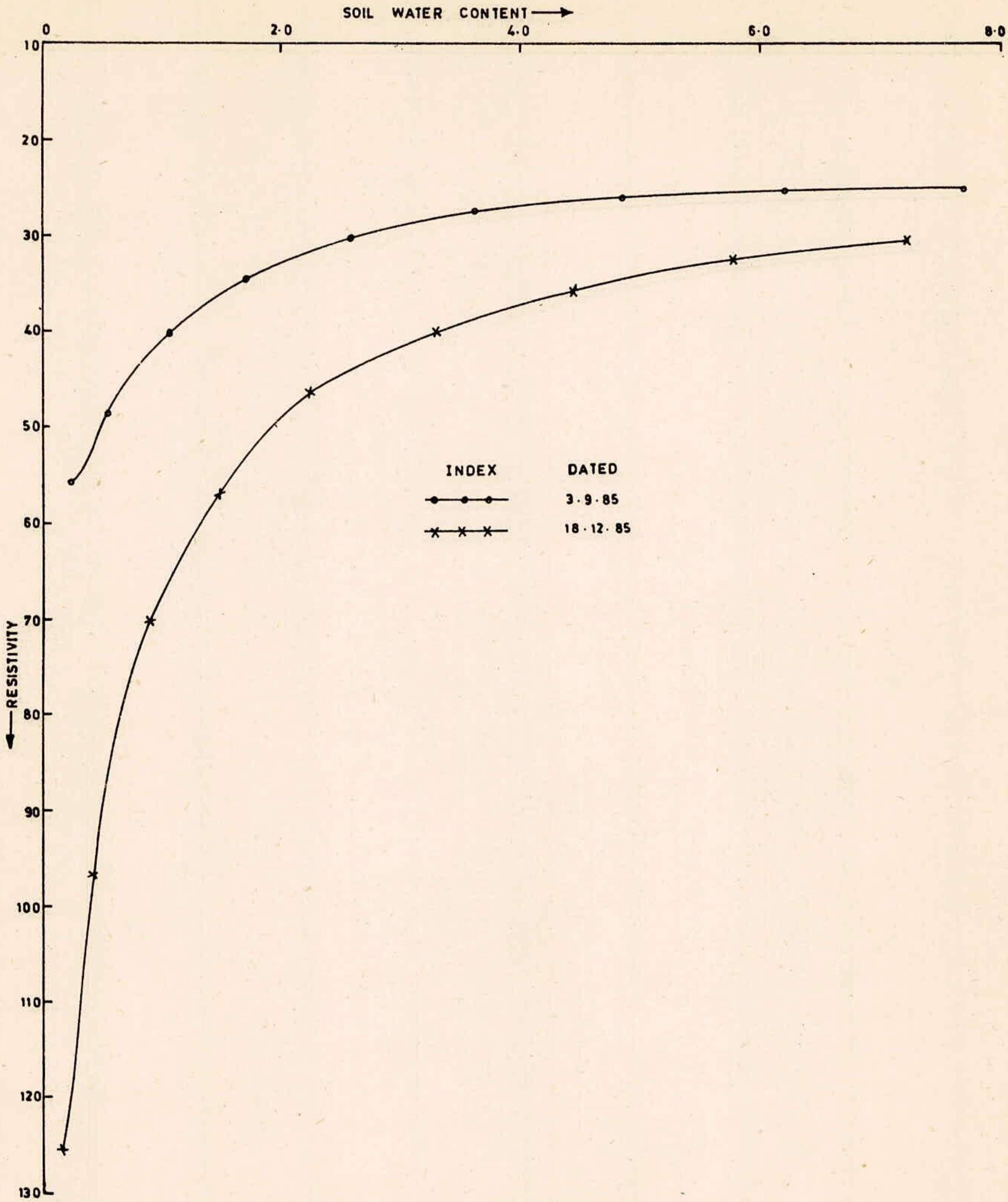


FIG. 8- TOTAL SOIL WATER CONTENT Vs RESISTIVITY

methods for rapid estimation of soil moisture. Preliminary of these investigations show an inverse relationship between soil moisture content and corresponding soil resistivity. It is proposed to have resistivity and soil moisture measurements for a longer period starting from premonsoon to post-monsoon months (May to January) for developing a strategy for employing surface resistivity technique for estimation and prediction of soil moisture on long term basis for soil water accounting etc.

7.0 CONCLUSIONS

Nuclear and resistivity methods were employed for studying variation of soil moisture and its effect on soil resistivity at the National Institute of Hydrology Campus, Roorkee. Data obtained for a limited period was analysed and preliminary results reported.

Results show that variation of soil moisture content of the top soil layers in unsaturated zone changes soil resistivity considerably. Distinct levels of resistivity for different soil moisture contents may help in estimation of moisture conditions using resistivity technique. It may be noted that effective utilization of resistivity technique requires resistivity measurements for extended periods.

Investigations carried out for a limited period indicate an inverse relationship between soil moisture content measured using neutron probe and corresponding soil resistivity observations. However, it would be necessary to carry out comprehensive study on these lines covering different type of soils and moisture conditions, for arriving at definit conclusion regarding applicability and efficacy of resistivity method for soil moisture estimation in top soil layer.

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