A Review on Physico-chemical and Dielectric properties of soil

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Abstract: The physico-chemical and dielectric characteristics of soil are thoroughly examined in this review study, with an emphasis on their importance for geotechnical applications, environmental monitoring, and agricultural production. The paper reviews the body of research on soil structure, density, porosity, texture, and moisture content and looks at the ways in which these physical characteristics affect the functionality and behaviour of the soil. The study also looks at the chemical characteristics of soil, which are important for soil fertility and plant growth. These characteristics include pH, cation exchange capacity, organic matter content, and nutrient availability. The dielectric characteristics of soil, which are essential for non-invasive soil sensing systems, take up a large amount of the text. In order to shed light on their respective contributions to soil dielectric behaviour, the dielectric constant and loss factor are examined in relation to soil temperature, salinity, and moisture content. The paper also discusses the methods used to quantify these attributes, assessing the accuracy and suitability of time-domain reflectometry (TDR), ground-penetrating radar (GPR), and capacitance sensors under various soil conditions. The combination of these attributes shows how the physical, chemical, and dielectric qualities of soil are related to one another and have an overall effect on managing and preserving soil health. In this review we have studies the physico-chemical properties of soil is based on various parameters like pH, electrical conductivity, temperature, moisture, soil organic matter, available nitrogen, phosphorus and potassium. This research review will create awareness among the farmers about economic productivity.

Introduction:-

Over the last two decades, microwave remote sensing has become a burgeoning field of research for analyzing natural resources. It delves into the interaction between electromagnetic waves and the objects under investigation. Grasping the dielectric properties of different earth materials at microwave frequencies is crucial in interpreting remote sensing data. The main factors influencing dielectric characteristics include component shape, frequency, porosity, texture, water saturation, and electrochemical interactions [7]. Planning a ground penetrating radar survey can benefit from high frequency dielectric measurements, while studying the behaviours of induced polarisation in materials can be aided by low frequency dielectric dispersion[3]. The only method by which we can ascertain the available nutrient status in the soil and formulate targeted fertilizer recommendations is through soil testing. In addition to providing detailed information on various soil parameters, soil characterization aids in identifying crop production constraints and soil potential [1]. number of methods for measuring the microwave dielectric constant and dielectric loss of liquids have been proposed by different research groups and the classic paper on the method of measurement is that of Roberts and Von Hippel in 1946 [2]. India is unable to afford to lose them as pure garbage. On the other hand, non-renewable resources are running out faster than they can be used due to the rising demand for raw materials for industrial production. As a result, efforts must be taken to reduce pollution caused by the disposal of garbage by turning it into raw materials that may be used for a variety of useful uses. The issues surrounding the disposal of industrial solid waste are linked to both an absence of infrastructure and an industry's failure to implement appropriate safety measures[17]. There are still certain systems in place for the disposal of solid waste for big and medium-sized companies situated in designated (conforming) industrial districts. With small-scale industries, the issue still exists. Small-scale enterprises find it easy to dispose of waste here and there in many cities and towns, which makes it difficult for local organisations to collect rubbish that is not their duty. Certain cities combine commercial, industrial, and residential districts; as a result, garbage from all sources is mixed together[21].

The material's dielectric characteristics are determined by the degree of dipole alignment with the applied time-varying electric field, ionic, conduction, and activity of permanent electrical dipoles. For non-homogeneous materials like soil, the molecular movement is influenced by the composition of the substance, which in turn impacts the dielectric characteristics. The complex

dielectric permittivity with respect to free space determines how electromagnetic fields interact [5]. The naturally occurring chemical components of soil, such as carbon, sodium, potassium, and iron, as well as its physical characteristics, such as sand, silt, and clay, determine its dielectric characteristics. When an electromagnetic field is applied to a dielectric medium, energy is released in the material due to the dielectric relaxation process. This process is used in the microwave soil dielectric measurement, where absorption of microwaves corresponds to the rotational energy of molecules [7]. Both beneficial and harmful processes contribute to soil formation. Broken rock fragments that have undergone chemical and mechanical changes due to weathering and erosion make up soil. The many functions of soil are advantageous to humans and other living things . A collection of mineral particles does not constitute soil. It has various other components as well as a biological system of living things. The development of soil is greatly influenced by the climate and other factors [15]. Using an open-ended coaxial probe approach, a high-temperature dielectric constant analyzer is used to measure the dielectric constants of the neutral leaching residue. A small amount of leaching slag is added to the sample tube, which is then placed inside a cylindrical resonant cavity with inner dimensions of 200 mm in diameter and 190 mm in height. Each sample is then used and uniformly compacted in a quartz tube, which has internal dimensions of 4.1 mm and height of 52 mm and is placed inside the holder cavity. Heating is done using an eddy current heating system. The permittivity measurement tests are conducted in an air atmosphere at a microwave frequency of 2450 MHz, with temperature increments of 100°C from room temperature to 1200°C [22]. The identification, inventory, and mapping of soils found on Earth's surface can be aided by remote sensing. The electrical characteristics of natural earth elements, such as soil and water, are closely related to their microwave remote sensing properties. The dielectric loss and dielectric constant are the two most crucial factors. Understanding dielectric constant and dielectric loss is useful when utilising microwave sensors to research contaminated soils that are both wet and dry [23].

Review of papers: Various techniques are available for measuring the dielectric constant at microwave frequencies, according to research by Joshi and Bapna P.C . Chaudhri H.C.& co-workers conducted a dielectric research at the X-band microwave frequency in 2008 on soils that were heavily laden with moisture. This study's findings demonstrate how the electrical characteristics of dry and wet soils differ. The complex dielectric constant of soils was found using the Two Point Method in their most recent work.4 Bapna P.C. and Joshi discovered that the

dielectric constant drops with increasing frequency, irrespective of the kind of soil and moisture content. The frequency dispersion qualities were present in every sample. Liquid water, air spaces, and soil particles make up wet soil. Water's dielectric constant, which is around 80, is determined by how well its molecules can align their dipole moment along an applied field. Water's dielectric constant decreases due to substances that prevent molecules from rotating, such as freezing or strong bonds with soil particles. Bound water refers to the tightly bound state of water molecules in the first molecular layers surrounding soil particles, which is caused by both osmotic and matric forces 3, 4. This leads to a low dielectric constant for bound water. A water molecule's matric forces rapidly decrease in distance from the surface of the soil particle. Free water is the term used to describe the ability of water molecules that are several molecular layers away from soil particles to flow freely within the soil medium. Free water has a high dielectric constant as a result. There are more bound than free water molecules in the soil below the transition wetness. As a result, soil has a low dielectric constant at lower moisture levels. The number of free water molecules rises quickly as the moisture content of the soil exceeds the transition point, which causes the dielectric constant to significantly increase. Since sand has a lower surface area per unit volume than clay particles, clay particles can hold onto more bound water molecules at given moisture content. M.D. Dhiware and co-worker studies on the measurement of dielectric properties of soil samples of Nasik region. They were collected the Soil samples from agricultural land of Nashik region and they identified that soils was categorized as loamy sand, sandy loam and clay loam. 14 M.D. Dhiware and co-worker observe the soil's texture affects the dielectric constant of Chandwad soil. It has been discovered that the soil texture has a significant influence on these variances. According to our findings, there is a positive link between the dielectric constant and sand and a negative correlation with silt and clay. Our findings demonstrate a strong positive relationship between electrical conductivity and dielectric constant.15 D. A. Boyarskii, V. V. Tikhonov, and N. Yu. Komarova gives Contradictions and debatable information regarding the physicochemical characteristics of water in contact with soil particles . The physical properties of bound water have not been well studied. Bound water was long thought to possess an ice-like structure. According to what is already known, the structure of the water layer is more deformed than that of free water and ice the closer it is to the particle . When compared to free water, the structure distortion of water near a surface (soil particles) results in changes in it.16 Manoj Kumar Tiwari , Dr. Samir Bajpai , Dr. U. K. Dewangan study Life is directly sustained by soil and its biota, which are vital

components of the earth's living skin (Wilkinson et al., 2009). A general conclusion that could be drawn from the examination of soil samples is that there are larger heavy metal concentrations in the soil close to the disposal or dumping site, and that these concentrations get lower the further away you go. Additionally, the depth-wise study revealed that the majority of the soil samples had higher amounts of particular heavy metals close to the ground's surface, with magnesium having the highest concentration. Additionally, the examination of surface water revealed that the amounts of Mn and Cr are higher both before and after the monsoon. Leachate contamination can be minimised through the use of liners in scientifically designed disposal sites, and if feasible, the production of industrial solid waste can be decreased by altering the processes of certain goods. When disposing of industrial solid waste or dumping it close to populated areas, appropriate alternatives can be employed because the higher pH (alkaline) of the discarded trash may also limit the production of leachate.17 Tajamul Aziz Alaie and Renu Gupta canclud that soil mapping by using GIS brings out the differences in soil fertility parameters across different land use, climate, and altitude within Doda district and in determining site specific nutrient management to maintain soil health .18. J. Wang, T. Schmugge, and D. Williams gives dielectric properties of several soil samples were measured as a function of moisture content. The measurements were performed at the frequencies of 5 and 19.35 GHz and thereby extended the frequency range of the measured data reported in the literature. There are two advantages in determining soil water content on a volume basis. First, the compactness factor of the soil sample in the waveguide was removed to a large extent, and the precision of the measurements improved in comparison to the case when moisture content was expressed in terms of percentage by dry-weight. Secondly, as also reported by Cihlar and Ulaby , the difference in the measured dielectric constants due to soil types was reduced, although the residual difference was still appreciable as shown by the measured data at 5 and 1.40 GHz

1. Physical properties:-

S. No	Sample	Sand %	Silt %	Clay %	Texture %	WHC %	PD %	BD %	Pore Specs %
1	Kelwa (Rajsamand)	88	3	8	Loamy Sand	14.5	23.34	1.62	53.5

	White Marble								
2	Keshriya ji (Dungerpur) Green marble	71	26	4	Sandy Loam	6.5	26.45	1.32	52.8
3	Babarmal (Udaipur) Pink Marble	87	9	3	Loamy Sand	74.2	25.4	1.42	51.6

2. Chemical analysis:-

S. No	Sample	pH	EC (dSm-1)	OC (%)	P2O5 (Kgha-1)	K2O (Kgha-1)	Ca m.eq/ltr	Mg m.eq/ltr	Na ppm	CaCO3 (%)
1	Kelwa (Rajsamand) White Marble	7.56	0.34	0.33	28.2	330.6	3.2	4.3	17.9	48
2	Keshriya ji (Dungerpur) Green marble	7.27	0.54	0.93	25.1	206.6	6.6	5.7	12.7	15
3	Babarmal (Udaipur) Pink Marble	7.01	0.42	0.38	21.8	358.1	6.7	2.3	21.1	11

Role of Physico-Chemical Properties in Soil Quality (19)

PH-One of the most crucial physical characteristics of soil is pH .It significantly affects the concentration and absorption of solutes in soil. For various reasons, including the fact that many

plants and soil life forms prefer either an acidic or an alkaline environment, soil pH is a crucial factor for farmers and gardeners to take into account.

Texture –Soil having different textural groups, on basis of the proportion of different sized particles. Soil texture directly influences soil-water relation, aeration and root penetration. It also affect on the nutritional status of soil. Soil texture can be expressed significantly by its electrical conductivity.

Moisture - Soil moisture is a crucial physical attribute. The soil's moisture content affects how well nutrients are absorbed. The texture and structure of soil are closely associated with its water content. Common factors influencing soil moisture include the void ratio, particle size, organic content, clay minerals, and ground water quality.

Soil temperature-(20) Soil temperature depends on the ratio of the energy absorbed to that lost. Soil has a temperature range between -20 to 60 °C. The temperature of the soil is the most important property because it shows its effect on the chemical, physical and biological processes related to growth of plants. Soil temperature changes with season, time of day, and local conditions of climate.

Nitrogen-The most important ingredient that plants take from the soil is nitrogen, which also acts as a growth bottleneck for plants . Nitrogen gas makes up almost 80% of the atmosphere. As nitrogen gas diffuses into the water, blue-green algae can "fix" (transform) it into ammonia for utilisation by the algae. Additionally, ammonia and inorganic nitrogen can find their way into lakes and streams. Aquatic systems have a plentiful amount of accessible nitrogen due to the variety of ways that nitrogen can enter these systems.

Phosphorus - One of the most crucial elements found in all living cells is phosphorus [13]. It is among the most crucial micronutrients required for the growth of plants. Most frequently, phosphorus acts as an energy storage agent and restricts the amount of nutrients that stay in plant nucleus.

Potassium- Potassium is a crucial component for the growth and development of plants, and it is involved in many physiological processes in plants [15]. It is engaged in a wide range of plant metabolic processes, including those that produce plant sugars that are utilised for a variety of plant metabolic requirements, regulate photosynthesis, and build lignin and cellulose, which are used to form cellular structural components.

Methods of measurement of dielectric properties:-

1. Wave guide method:-

By computing the shift in minima of the standing wave pattern inside the waveguide, the dielectric constant is determined using the wave guide method. When dielectric material is added to the wave guide, the guide wavelength shifts, causing the shift.

2. Cavity method:-

This technique makes use of a cylindrical cavity resonator. The mode chart, which is a family of straight lines when (Fd2) is plotted against (D/L2)—where f is the frequency, D is the cavity's diameter, and L is its length—is used to construct the cavity. In the TE011 mode, the operational rectangle operates between 7.1 and 8.8 GHz in frequency.

3. Network analyser method:-

By simply touching the co-axial probe of the network analyser to the flat face of the soil surface, the dielectric constant of the sample is measured using this method. The components of the system are a network analyzer (HP8510C), a sweeping radio frequency source, and related data processing equipment.

4. Infinite sample method:-

It is challenging to test dielectric materials with extremely high loss tangents using the standard technique for low- and medium-loss materials. This is because, on the one hand, a very short sample will result in a considerable measurement error; on the other hand, a longer sample will not significantly alter the output data due to a change in the terminal impedance. A dielectric

sample may be deemed infinitely long if it can physically dissipate a significant enough percentage of the microwave radiation that enters it, preventing any energy from being reflected into the in-pot. When this circumstance presents itself as a relatively straightforward measurement technique that essentially simply requires determining the normalised input impedance at the sample face, it might be advantageously utilised.

Conclusion:

To meet human need for food, conventional agriculture has relied heavily on chemical inputs, which is a significant factor in increasing food yield. The majority of farmers have been using excessive amounts of pesticides and fertilisers in recent years. Overuse of chemicals results in a decline in soil quality. Due to extensive usage of pesticides and fertilisers, small crops were also impacted. Analysis of soil parameters is therefore crucial. The information above assists farmers in maintaining the ideal concentration of all the nutrients that are vital to plants through the use of integrated nutrient management practices.

Indian soil's dielectric characteristics are dependent on its texture; a notable positive association between the dielectric constant and the amount of sand in the soil and a negative correlation with the amount of clay and silt was found. Dielectric characteristics and gravimetric water content have a nonlinear connection. As a result, it is clear that a variety of parameters, including frequency, moisture, and the physical and chemical composition of the soil, affect its dielectric constat.

References:-

1. V. Navarkhele*, A. A. sheikh 1 & R. S. Ramshetti 2 dielectric properties of black soil with organic and inorganic matter at microwave frequency journal of radio & space physics vol. 38, April 2009, pp. 112-115

2. C. H. Chaudhri dielectric properties of soil of organic and inorganic material j- band microwave frequency. Int. J. Remotesens. Geosci. 4, 14-19 (2015)

3. Rajesh. Mohan. R, . M., p. Mohanan. Study and analysis of dielectric behavior of fertilized soil at microwave frequency. Euro. J. Adv. Engg. Tech2, 73-79 (2015).

4. Chaudhri, H. C. Dielectric properties of soils with inorganic matter at s-band microwave frequency. IJCS 3, 59- 66 (Nov-Dec 2014).

5. H. C. Choudhri, V. J. Shinde. Dielectric properties of soil at x-band microwave frequency. Indian j. Pure appl. Phys.50, 64-66 (2012)

6. Bapna P. C., Joshi. S. Measurement of dielectric constant of soils of marble mining areas of Mewed region, Rajasthan state at x-band. Ijetee3, 66-69 (May-2013.).

7. Buliya, a. Complex dielectric permittivity of salt effected soil at lower microwave frequency. Indian j.sci.res.3, 127-130 (2012).

8. H.C. Choudhri, V. J. Shinde. Dielectric properties of black and red soil at microwave frequency. Indian j. Radio space phys. 39, 103-106 (April 2010).

9. H. Gadani, a. D. V. Measurement of complex dielectric constant of soils of Gujarat at x- and c-band microwave frequencies. Indian J. Radio space phys. 7, 221-229 (June 2008).

10. Chaudhari. H. C, Shinde. V. J. Dielectric study of moisture laden soils at x-band microwave frequency. Int. J. Phys. Sci.3, 075-078 (March, 2008)

11. O p n calla comparative study of the method of measurement of dielectric constant at microwave frequency of dry and wet soil . Indian j. Radio space phys.108-113(Vol 32 ,April 2003)

12. M.D. Dhiware , S. B. Nahire , Sushant Deshmukh, Physico-chemical and Dielectric properties of soil samples at X-band microwave frequency of Nasik region .

13. Journal of Pure Applied and Industrial Physics, Vol.9(5),40-55, May 2019 (An International Research Journal), www.physics-journal.org 40 Review of Literature on Microwave Remote Sensing and Dielectric Behaviour of Soil in India Nitesh Kumar1 , A. C. Paul1 , M. Z. Khan2 , A. K. Shrivastava2 and A.Pandey2

14. Relationship of Electrical Conductivity and Dielectric Constant With Status of Micronutrients in The Soil of Northern Maharashtra Region M. D. DHIWARE1 , S. B. NAHIRE2 , S. B. DESHMUKH3*

15. Progress In Electromagnetics Research, PIER 35, 251–269, 2002 MODEL OF DIELECTRIC CONSTANT OF BOUND WATER IN SOIL FOR APPLICATIONS OF MICROWAVE REMOTE SENSING D. A. Boyarskii, V. V. Tikhonov, and N. Yu. Komarova

16. International Journal of Scientific and Research Publications, Volume 5, Issue 7, July 2015 1 ISSN 2250-3153 www.ijsrp.org An Analytical Study of Heavy Metal Concentration in Soil of an Industrial Region of Chhattisgarh, central India Manoj Kumar Tiwari , Dr. Samir Bajpai , Dr. U. K. Dewangan .

17. Original Research Article https://doi.org/10.20546/ijcmas.2019.806.098 Assessment of Soil pH, EC and OC in Different Land Use Systems of Doda District, J&K, India Tajamul Aziz Alaie* and Renu Gupta

18. NASA Technical Paper 1238 I 238- 1; -v.z ', c:. , j I Dielectric Constants of Soils at Microwave Frequencies - I1 \ / . J. Wang, T. Schmugge, and D. Williams MAY 1978

19. Chemical Science Review and Letters ISSN 2278-6783 Chem Sci Rev Lett 2015, 4(13), 57 - 66 Article CS29204512 57 Review Article A Review on Role of Physico-Chemical Properties in Soil Quality Ku. Smita Tale* 1 and Dr. Sangita Ingole2

20. International Journal of Chemical Studies 2015; 3(4): 29-32 Physico-chemical properties of soil SS Kekane, RP Chavan, DN Shinde, CL Patil, SS Sagar

21. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Published by, www.ijert.org NCACE - 2016 Conference ProceedingsImpact of Solid Industrial Waste on Soil Mukul Nama, Dhrindra Singh, Dileep Kumar Dhobi, Gaurav Sharma, Deepak Vaisnav

22. Yongguang Luo, Tianqi Liao, Xia Yu, Jing Li*,§, Libo Zhang*,§ and Yunhao Xi Dielectric properties and microwave heating behavior of neutral leaching residues from zinc metallurgy in the microwave field https://doi.org/10.1515/gps-2020-0011 Received August 13, 2019; accepted October 22, 2019

23. International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 5, Issue 4, April 2016 Copyright to IJIRSET DOI:10.15680/IJIRSET.2016.0504088 5742 Dielectric Properties of Contaminated Soils at X-band Microwave Frequencies Nima P. Golhar1 , P. R. Chaudhari2