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Variation of Emissivity and Scattering Coefficient of Soils with Incident Angle and Moisture Content at C-Band frequency

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Abstract- This study presents experimental measurements of dielectric constant of dry and moist soils at C-band microwave frequency by using waveguide cell method. Soil samples were collected from four locations each from four different Indian states. An automated microwave set-up operating at 5.3 GHz frequency is used for this purpose. Measured values of dielectric constant are then used to estimate emissivity and scattering coefficient by using emissivity model and perturbation model respectively. Emission and scattering properties for soils are then studied as function of gravimetric Moisture Content (MC, %), polarization and incidence angle. At constant value of MC, emissivity of soil is found to increase with increase in the incident angle for vertical polarization, and this increase continues up to Brewster's angle and beyond this, emissivity decreases sharply. Further, at constant value of MC, scattering coefficient of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to angles between 60^o to 70^o, at which it reaches maximum value and beyond this, it decreases sharply. In case of horizontal polarization, at constant value of MC, emissivity and scattering coefficient decreases with the increase in incident angle. Further, scattering coefficient of soils show increase with increase in MC whereas its emissivity decreases with increase in MC. Results of this study may find uses in the design of passive and active remote sensors for such soil types.

Index Terms- Dielectric constant, emissivity, scattering coefficient, horizontal and vertical polarizations, soil

I. INTRODUCTION

Remote sensors measure electromagnetic (EM) radiation that has interacted with the Earth's surface. Interactions of EM radiation with soils can change its direction, intensity, wavelength and polarization. The nature of these changes is dependent on the dielectric and also physico-chemical properties of these soils exposed to the EM radiation. In recent years, many research efforts have focused on the development of remote sensing techniques to map soil moisture content at a large scale and with adequate resolution [1-3].

Emission and scattering behavior of soils depends upon the dielectric constant, moisture content, chemical composition, surface roughness, physical temperature, frequency, incident angle and polarization. Thus natural objects have different scattering coefficients depending on their physical and electrical properties. The surface smoothness of the target is found to have a great effect in this case. If the surface is very smooth, the power will be highest in the direction of the reflection angle. On the other hand, if the surface is very rough, it will be scattered in all the directions. This roughness parameter is usually defined in relation to the wavelength.

Several investigators have studied the emission and scattering behaviour of soils by measuring their dielectric constant. The studies on dielectric properties of soils at microwave frequency having different textures were carried out by O. P. N. Calla et al. [4] and Ahire D. V. et al. [5]. Further, the emissivity and scattering coefficient of different soils as function of their type, texture, MC (%), frequencies, polarization and incidence angles have been studied experimentally by several investigators [6-13]. Results of all these investigations confirm that the variations of emissivity and scattering coefficient have inverse trends.

In the present experiments, the dielectric constants of dry and wet soil samples are measured at 5.3 GHz microwave frequency using waveguide cell method. Four Top-Soil samples were collected from various locations each from four different Indian states. Results of dielectric constant are then used to estimate the corresponding values of emissivity and scattering coefficients of soils. Such study of emission and scattering behaviour of soils having various MC (%) and for incident angles varied from 0^o to 80^o will be helpful for designing of passive and active microwave remote sensors for such soils. Physical and chemical properties of these four soil samples are also measured. This confirms the need and importance of the research work reported in the present study. This study would also provide a feedback to RISAT-1 application programme for remote sensing and agriculture.

II. MATERIALS AND METHODS

A. Study Areas and Soil Sampling Techniques

Soil is a heterogeneous body. Therefore, it is not possible to collect a soil sample which would be representative of the heterogeneous land. So, first of all the heterogeneity of the land is minimized by dividing the land into smaller units. It is, therefore, important that samples are representative of the soil for the area under investigation. Unless this is ensured, sampling may be the greater source of error in the whole process. Moreover, variations of slope, colour, texture and management practices should also be taken into account and separate sets of composite samples should be collected from each such area. In the present investigations, we have collected four Top-Soil samples from four locations each from four different Indian states. These samples have depths ranging between 0-20 cm. Different sites visited for collecting these soils and the physical and chemical properties of these soil samples are given in Table-1. For convenience, the soil samples are numbered in accordance with decrease of their percentage of clay contents. Expect sample No.3 which is slightly acidic, rest of the three samples are slightly alkaline in nature.

Sample No.	**Soil sampling site (State)**	**Soil Texture (%)**			**Text-ural Class**	**Soil Colour**	**pH (1:2.5)**	**EC (dS m^{-1})**	**N**	**P**	**K**
		Sand	**Silt**	**Clay**					**(Kg.ha^{-1})**		
1.	Muddur (Karnataka)	31	22	47	Clay	Black	7.4	0.21	251	3	738
2.	Indore (Madya Pradesh)	19	40	41	Clay	Faint Black	7.9	0.08	100	35	307
3.	Roorkee (Uttara khand)	67	20	13	Sandy Loam	Creamy White	6.9	0.1	151	6.1	133
4.	Coimbatore (Tamilnadu)	88	4	8	Sand	Deep Red	7.1	0.08	94	6.4	123

Table 1: Physical and chemical properties of soil samples

B. Preparation of Soil Samples

Topsoil samples were collected from agricultural land of desired locations/sites. These topsoil samples are first sieved by gyrator sieve shaker (size 425 μm) to remove the coarser particles. The sieved out fine particles are then dried in the hot air oven to a temperature around 110^{o}C for about 24 hours in order to completely remove any trace of moisture. Such dry samples are then called as oven-dry or dry base samples when compared with wet samples. Soil samples of various gravimetric moisture contents (upto 25%) are prepared by adding an exact amount of distilled water to the known mass of the oven dry soil. The single pan precision balance having digital readout accuracy of 0.1 mgm is used for weighing the sample. The soil-water mixtures are well mixed and are kept in a closed container for proper settling over several hours. These samples of desired gravimetric MC(%) are then inserted into the solid dielectric cell for measuring their dielectric properties.

C. Dielectric Constant Measurement

The wave-guide cell method is used to determine the dielectric constant of the soil. An automated microwave set-up is used in the TE_{10} mode with Gunn source operating at C-band (5.3 GHz) frequency. PC-Based slotted line control and data acquisition system are used for this purpose. It consists of Microcontroller (8051) and ADC-12 Bit- MCP (3202) Visual-Based software. The sample lengths are usually taken in the multiples of λ/4. The solid dielectric cell with the soil sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the soil sample. The sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. This standing wave pattern is then used for determining the values of shift in minima resulted due to before and after inserting the soil sample. The dielectric constant is calculated by measuring the standing wave ratio of the dielectric material and the shift in minima of the standing wave pattern in a rectangular waveguide. This shift takes place due to change in the guide wavelength when a dielectric material is introduced in waveguide. Using the value of dielectric constant of soil samples having different MC (%), the estimations of emissivity and scattering coefficient are made. Dielectric constant (ε') and loss (ε'') are determined by using the equations

$$\varepsilon' = \frac{g_{\varepsilon} + (\lambda_{gs} / 2a)^2}{1 + (\lambda_{gs} / 2a)^2} \quad (1)$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1+\left(\lambda_{gs}/2a\right)^2} \tag{2}$$

Where, a = Inner width of rectangular waveguide.
λ_{gs} = wavelength in the air-filled guide.
g_ε = real part of the admittance
β_ε = imaginary part of the admittance

D. Estimations of emissivity by using emissivity model

In this paper, the emissivity model is used for estimation of emissivity from the measured valves of dielectric constant for soils. Because this model is simple to use and it gives reasonable accuracy [6]. The basic expression for emissivity is

$$e_p(\theta) = 1 - r_p(\theta) \tag{3}$$

Where,
$e_p(\theta)$ = Emissivity of the surface layer
p = Polarization either vertical or horizontal,
$r_p(\theta)$ = Reflection coefficient

In case of smooth surface over a homogeneous medium $r_p(\theta)$ can be obtained from Fresnel reflection coefficient $R_p(\theta)$ as

$$r_p(\theta) = |R_p(\theta)| \tag{4}$$

Fresnel reflection coefficient for horizontal polarization is given by

$$R_p(\theta) = \frac{\cos\theta - \sqrt{(\varepsilon' - \sin^2\theta}}{\cos\theta + \sqrt{(\varepsilon' - \sin^2\theta}} \tag{5}$$

and, for vertical polarization it is

$$R_p(\theta) = \frac{\varepsilon'\cos\theta - \sqrt{(\varepsilon' - \sin^2\theta}}{\varepsilon'\cos\theta + \sqrt{(\varepsilon' - \sin^2\theta}} \tag{6}$$

Eqs. (3)-(6), are used to estimate the emissivity of soils having various MC (%) for vertical and horizontal polarizations by knowing their values of dielectric constants.

E. Estimations of scattering coefficient by using perturbation model

Different models are to be used depending on the nature of the surface. For waveguide cell method, the surface of the soil inside the waveguide is smooth, hence the perturbation model is quite suitable [14-15]. The perturbation method requires the surface standard deviation to be less than about 5% of the electromagnetic wavelength. Accordingly, in the present case, the surface standard deviations for C- band is about 1.4 mm. The corresponding surface correlation length is around 13.2 mm. In order to apply perturbation model, the necessary conditions to be satisfied are

$$K\sigma < 0.3$$

And

$$\frac{\sqrt{2}\,\sigma}{l} < 0.3$$

Where,
k = Wave number = $2\pi/\lambda$
σ = Surface standard deviation
l = Surface correlation length
In the present case

$k\sigma = 0.15$ and $kl = 1.0$

The backscattering coefficient is given by

$$\sigma^{\circ}_{ppn}(\theta)=8K^4\sigma^2\cos^4\theta\times|\alpha_{pp}(\theta)|^2 W(2K\sin\theta) \quad (7)$$

$p = v$ or h

where, $|\alpha_{hh}(\theta)|^2 = \Gamma_h(\theta)$ (8)

$$\alpha_{vv}(\theta) = (\varepsilon' - 1)\frac{[\sin^2\theta - \varepsilon'(1+\sin^2\theta)]}{[\varepsilon'\cos\theta + (\varepsilon' - \sin^2\theta)^{1/2}]^2} \quad (9)$$

$|\alpha_{hh}(\theta)|^2 = \Gamma_h(\theta)$ is the Fresnel reflection coefficient for horizontal polarization.

$$\alpha_{hh}(\theta) = \frac{\cos\theta - \sqrt{(\varepsilon' - \sin^2\theta)}}{\cos\theta + \sqrt{(\varepsilon' - \sin^2\theta)}} \quad (10)$$

and W (2Ksinθ) is the normalized roughness spectrum, which is the Bessel transform of the correlation function ρ(ξ), evaluated at the surface wave number of 2Ksinθ.
The normalized roughness = W (2Ksinθ), is given by the following equation

$$W(2K\sin\theta)=0.5l^2\exp[(kl\sin\theta)^2] \quad (11)$$

Eqs. (7)-(11), are used to estimate the scattering coefficient of soils having various MC (%) for vertical and horizontal polarizations by knowing their values of dielectric constants.

III. RESULTS AND DISCUSSION

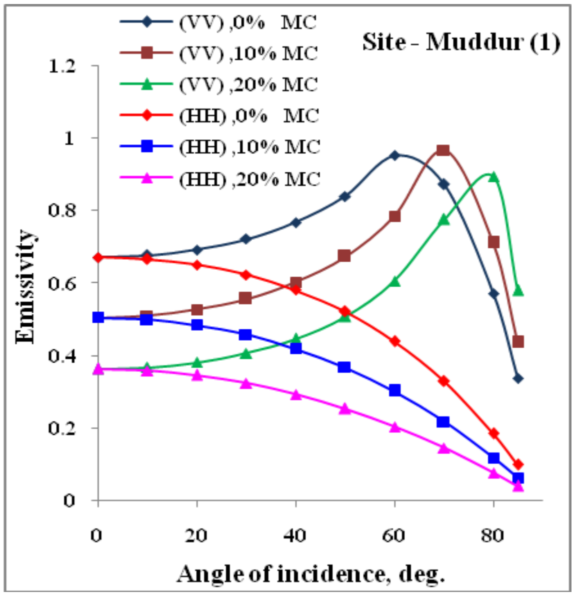
The results on dielectric, emissive and scattering parameters for the four soil samples having different moistures studied at 5.3 GHz microwave frequency are presented in tabular and graphical forms. Table 2 shows the variation of dielectric constant (ε') of four soil samples having percentage gravimetric moisture contents (0-25%). It shows strong dependence of (ε') of these soil types on MC (%). Dielectric constant of these soil samples increases with increase in the MC (%). The variation is non-linear and its rate of increase is relatively higher for MC in the rage 10-20%. This is due to resonance absorption of microwave energy by water molecules over the range of frequency used and hence our results are in close agreement with the results of quoted by earlier investigators [10,11].

Table 2: Variation of dielectric constant (ε') of four soil samples with percentage gravimetric moisture contents at 5.3 GHz frequency

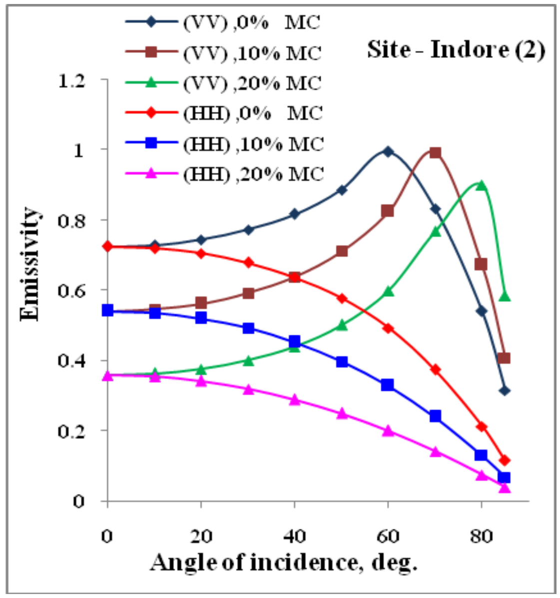
Moisture Content (%)	**Dielectric constant, ε'**			
	Muddur (1) (Karnataka)	**Indore (2) (Madhya Pradesh)**	**Roorkee (3) (Uttarakhand)**	**Coimbatore (4) (Tamilnadu)**
0	3.94	3.1	2.8	3
5	5.9	4.6	4.36	5.49
10	8.82	7.3	7.25	7.89
15	10.55	15.7	11	11.3
20	20.45	21	16.8	18.1
25	20.15	21.5	17.9	19.5

Fig. 1 (a) to (d) shows the variation of emissivity, $e_p(\theta)$ of four soil samples with MC (%) and different angle of incidence for horizontal and vertical polarizations at 5.3 GHz frequency. It is observed that at constant value of MC, emissivity of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to a certain look angle referred to as 'Brewster's angle', at which it reaches maximum value equal to unity; and beyond this particular angle, emissivity decreases sharply. Further, for vertical polarization, at constant value of incident angle, emissivity of soil sample is found to decrease significantly with increase in the values of its MC (%).

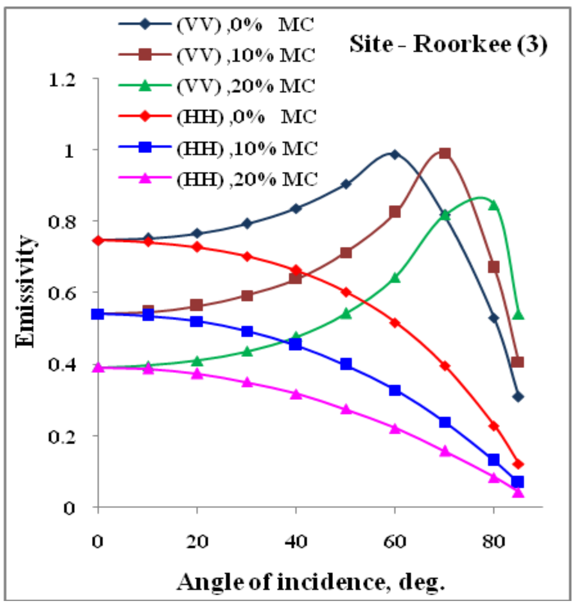
In general, in case of horizontal polarization, the value of emissivity for these soil samples decreases with the increase in incident angle. It is further observed that the magnitudes of emissivity of soils at same incident angle are greater for vertical polarization than for horizontal polarization. Further, for horizontal polarization, at constant value of incident angle, emissivity of soil sample is also found to decrease significantly with increase in the values of its MC (%), similar to vertical polarization. Thus, results presented here show fairly good agreement with the experimental results and theoretical predictions of earlier investigators [6,10,12].



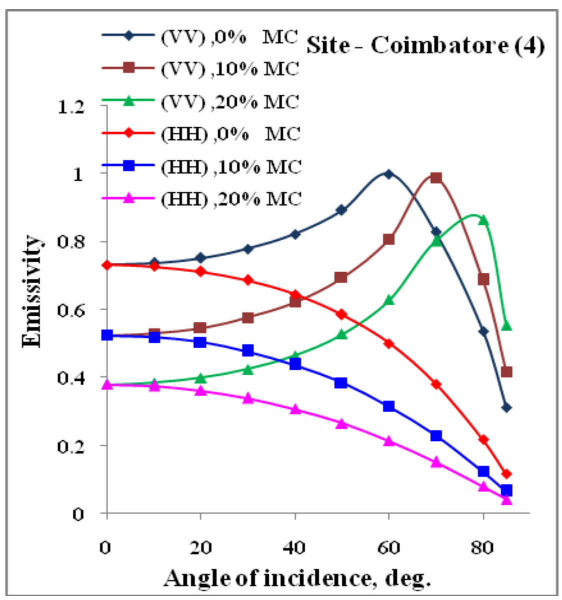
(a) For Soil Sample No. 1 (Muddur Site)



(b) For Soil Sample No. 2 (Indore Site)



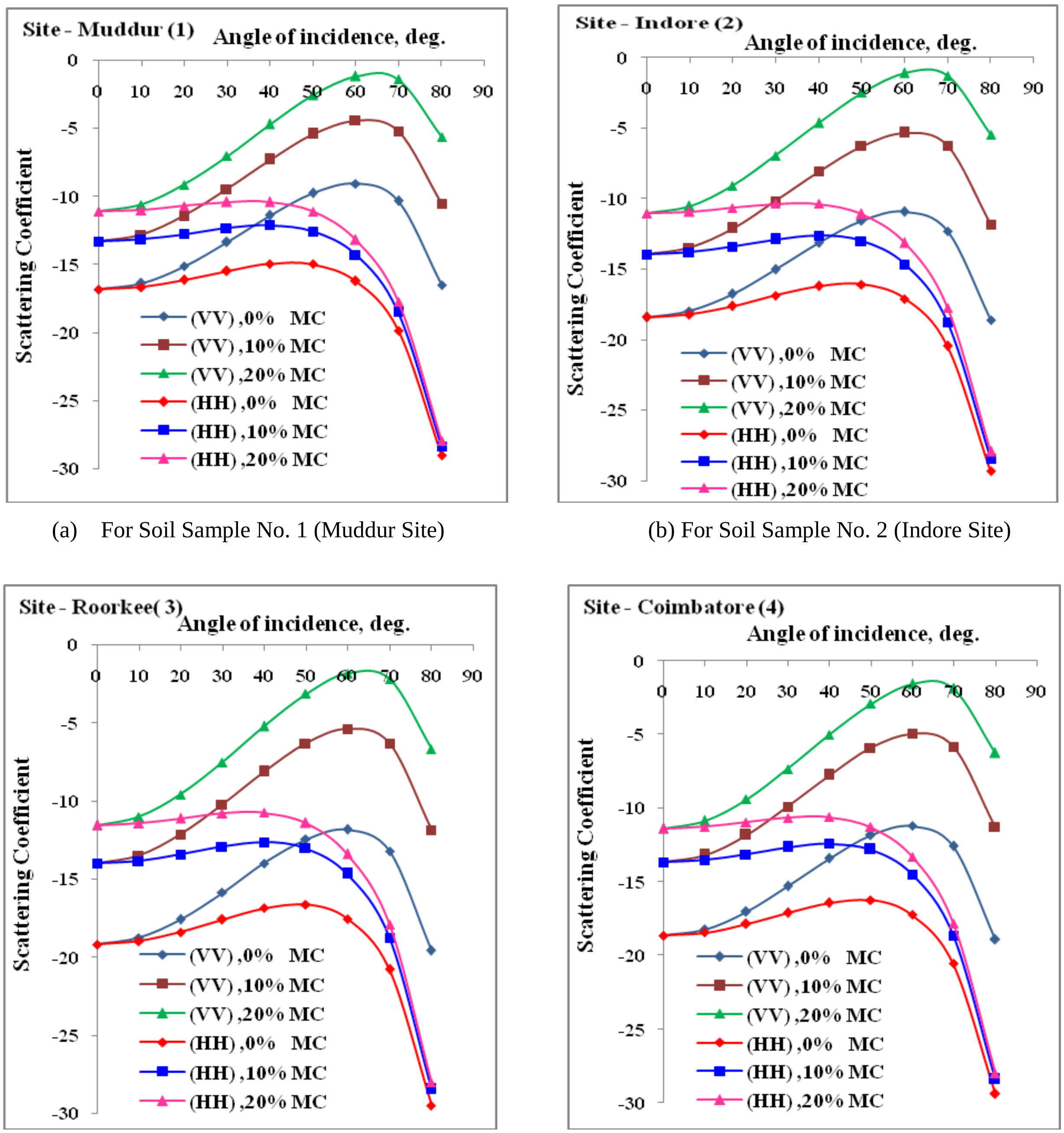
(c) For Soil Sample No. 3 (Roorkee Site)



(d) For Soil Sample No. 4 (Coimbatore Site)

Figure 1: Variation of emissivity (vertical and horizontal polarizations) of soils with incident angles for various moisture contents at microwave frequency, 5.3 GHz.

Fig. 2 (a) to (d) shows the variation scattering coefficient of four soil samples with MC (%) and different angle of incidence and having three different MC (0%, 10 % and 20 %) for vertical and horizontal polarizations at 5.3 GHz frequency. It is observed that at constant value of MC, scattering coefficient of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to angles between 60^o to 70^o, at which it reaches maximum value and beyond this particular angle, scattering coefficient decreases sharply. Value of this angle is found slightly more for higher MC. Further, for vertical polarization, at constant value of incident angle, scattering coefficient of soil sample is found to increase significantly with increase in the values of its MC (%).



(a) For Soil Sample No. 1 (Muddur Site)

(b) For Soil Sample No. 2 (Indore Site)

(c) For Soil Sample No. 3 (Roorkee Site)

(d) For Soil Sample No. 4 (Coimbatore Site)

Figure 2: Variation of scattering coefficient (vertical and horizontal polarizations) of soils with incident angles for various moisture contents at microwave frequency 5.3 GHz.

In case of horizontal polarization, the value of scattering coefficient for soil sample almost remains constant up to incident angles about 40-50° and then starts decreasing slowly. Beyond 50°, it decreases significantly with increase in the incident angle and at about 70-80° and, thereafter values of scattering coefficient becomes almost equal for all three MC. Thus, in general, for horizontal polarization, scattering coefficient decreases with the increase in incident angle. It is further observed that the magnitudes of scattering coefficient of soils at same incident angle are greater for vertical polarization rather than for horizontal polarization. However, for horizontal polarization, at constant value of incident angle, scattering coefficient of soil sample is also found to increase significantly with increase in the values of its MC (%), similar to vertical polarization. Thus, results presented here show fairly good agreement with the experimental results and theoretical predictions of earlier investigators [7-12].

The results presented on dielectric constant, emissivity and scattering coefficient in Table 2, Fig. 1 and Fig. 2 respectively, for dry and moist soil samples of four different states studied at different incidence angles have more or less similar trends in their variations. The small deviations observed in these results may be due to differences in the texture and other physico-chemical properties of four soil samples. The results of this study on emissivity and scattering coefficient are quite useful in designing passive and active sensors respectively. Such sensors are very much needed for the study and interpretation of data of soils obtained by remote sensing satellites. Hence the reported study may find uses in various fields mainly in agriculture.

IV. CONCLUSIONS

- Dielectric constant of soil samples increases with increase in the MC (%) and this variation is non-linear.
- For vertical polarization, at constant value of incident angle, emissivity of soil is found to decrease with increase in its MC (%).
- It is further observed that the magnitudes of emissivity of soils at same incident angle are greater for vertical polarization than for horizontal polarization.
- At constant value of MC, scattering coefficient of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to angles between 60^o to 70^o, at which it reaches maximum value and beyond this, it decreases sharply.
- In case of horizontal polarization, at constant value of MC, emissivity and scattering coefficient decreases with the increase in incident angle.
- For vertical and for horizontal polarization, at constant value of incident angle, scattering coefficient of soil sample is found to increase significantly with increase in its MC (%). However, the magnitudes of scattering coefficient of soils at same incident angle are greater for vertical polarization than for horizontal polarization.
- Variations of emissivity and scattering coefficient of soil samples with MC% show inverse trends.

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REFERENCES

[1] W. Wagner, V. Naeimi, K. Scipal, R. Jeu, and J. Martínez-Fernández, "Soil moisture from operational meteorological satellites," *Hydrogeol. J., vol.* 15(1), 2007, pp121-131.

[2] R. A. M. De Jeu, W. Wagner, T. R. H. Holmes, A. J. Dolman, N. C. van de Giesen, and J. Friesen, "Global soil moisture patterns observed by space borne microwave radiometers and scatterometers," *Surv. Geophys. Vol.* 29(4-5), 2008, pp399-420.

[3] H. M. J. P. Barré, B. Duesmann, and Y. H. Kerr, "SMOS: the mission and the system," *IEEE Trans. Geosci. Rem. Sens*., vol. 46, 2008, pp587-593.

[4] O. P. N. Calla, V . Ranjan, C. Bohra, G. L. Naik, W. Hasan and H. S. Bali, "Estimation of dielectric constant of soil from the given texture at microwave frequency", *Indian J Radio and Space Phys,* vol. 33, 2004, pp196-200.

[5] D.V.Ahire, P.R.Chaudhari, Vidya D. Ahire, A. A. Patil, "Correlations of electrical conductivity and dielectric constant with physico- chemical properties of black soils", *International J. of Sci. and Res. Publications,vol.* 3(2), 2013, pp1-16.

[6] O. P. N. Calla and B. Deka, "Study of emissivity of dry and wet loamy sand soil at microwave frequencies", *Indian J Radio and Space Phys, vol.* 28, 2000, pp140-145.

[7] O. P. N. Calla and I. Hannan, "Estimation of scattering coefficient dry and wet soil with different moisture content at microwave frequencies", *Indian Journal of Radio and Space Physics,* vol. 30, 2001, pp106-111.

[8] O. P. N. Calla and S. Sharma, "Estimation of scattering behavior of dry and wet soil with undulating surface at microwave frequencies", *Indian Journal of Radio and Space Physics, vol.* 30, 2001, pp332-336.

[9] O. P. N. Calla, A. Baruah, B. Das, K. P. Mishra, M. Kalita and S. S. Haque, "Emission and scattering behavior of dry soils from northeast India" *Indian Journal of Radio and Space Physics,* vol. 33, 2004, pp321-328.

[10] O. P. N. Calla and H. S. Kalita, "Estimation of scattering coefficient of saline soil for slightly rough surface and undulating surface at microwave frequencies", *Indian Journal of Radio and Space Physics,* vol. 33, 2004, pp405-410.

[11] A. K. Fung, Z. Li and K. S. Chen, "Backscattering from a randomly rough dielectric surface", *IEEE Trans Geoscience & Remote Sensing (USA),* vol. 30, 1992, p356.

[12] V. K. Gupta and R. A. Jangid, "Microwave response of rough surfaces with auto-correlation functions, RMS heights and correlation lengths using active remote sensing", *Indian Journal of Radio and Space Physics,* vol. 40, 2011, pp137-146.

[13] F. T. Ulaby, "Radar measurement of soil moisture content", *IEEE Transaction on Antennas and Propagation,* AP-12, 1974, pp257-265.

[14] F. T. Ulaby, K. Sarabandi, K. Mcdonald, M. Whrrt and M. D. Dobson, "Michigan microwave canopy scattering model", *International Journal of Remote Sensing, vol.*11, 1990, pp1223-1253.

[15] S. Li, L. M. Wang, 1 H. Deng, Q. B. Zhou, Z. C. Li, "Inversion model research of soil surface roughness by using microwave remote sensing" *Proc.Dragon 1 Programme,* ESA SP-655, 2008.

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