JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Study of Dielectric Parameters of Soil Under Different Water Holding Moist Conditions

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Abstract: The real (ε') and imaginary part (ε'') of the dielectric constant of soil at different moisture states have been determined at a single microwave frequency of 10.0 GHz with an empirical model. Different moisture states are related to the water holding capacity of soil. The critical moisture states of soil considered in present investigation are such as: moisture-free (dry), hygroscopic level, permanent wilting point, field capacity, transition moisture and saturated level are considered. The Soil Moisture Content (SMC) corresponding to these moisture states is obtained by different model equations. In these model equations, the SMC is related to the soil texture. Two types of sandy loam samples are used for the estimation of the real and imaginary parts of the dielectric constant. Both soil samples (sandy loam) are differentiated according to their textural composition.

***Index Terms* - Dielectric constant, soil moisture content, water holding states of soil.**

I. INTRODUCTION

The study of SMC has enormous importance in various environmental studies like meteorology, hydrology, agriculture and climatology. The role of soil moisture in the top one to two centimeters of the earth's surface is widely recognized as a key parameter plays an extremely important role in various environmental processes. The dielectric properties of a soil depend on a number of factors, but SMC is the prime factor [1-3]. According to Schmugge *et al* [4] the significant influence on the dielectric constant of the soil is due to SMC and the effect of other parameters (texture, temperature, bulk density and salinity etc.) are function of the moistness of the soil. Ulaby *et al* [3] studied that at 1.0 GHz and at room temperature ε' and ε'' water are approximately 80.0 and 4.0 while the value of ε' for dry soil varies from 2.0 to 5.0 and the value of ε'' is typically less than 0.05. The large contrast between the dielectric constant of water and dry soil results in a range from 4.0 to 40.0 for dielectric constant of moist soil. This wide range can be directly related to the presence of volumetric SMC, and is further influenced by soil texture, frequency, temperature and salinity. The direct relation between soil bulk dielectric constant and volumetric soil water content is not straightforward and many empirical and theoretical dielectric models are suggested by various researchers [5-7]. The large difference between the dielectric constant of dry soil and moisture makes it possible to the measurement of SMC by the microwave techniques. Thus, presence of small amount of moisture produces considerable changes in the dielectric constant of soil. The observables of microwave remote sensing at the sensor (radar and radiometer) are strong function of dielectric constant of soil which is primarily controlled by SMC. Particularly, sensing in the microwave region may deduce spatial soil moisture information as the detected microwave signal is influenced by the dielectric properties of the soil, and thus the moisture content. Beside the use of SMC for meteorological or climate studies, hydrologic process studies, knowledge of SMC is fundamental requirement in many applications in the field of forestry, water and soil management, drought and flood forecasting and civil engineering. The amount of available water in a given soil has a profound effect on the productivity of the soil for agricultural use. SMC serves a critical role in shaping the ecosystem response to the physical environment. Near-surface soil moisture controls the partitioning of available energy at the ground surface into sensible and latent heat exchanges with the atmosphere, thus linking the water and energy balances through the moisture and temperature states of the soil.

The amount of water retained by soil at various moist conditions depends on the size and arrangement of the soil pores. In coarse and loose soils, water tends to drain away by gravity, leaving a small residue. Fine-textured soils usually have a greater total porosity, and thus retain larger amounts of water than do coarse-textured soils. Water is retained by soil within this pore system. Only about two-thirds of the water retained by the soil after the excess has been drained away by gravity is available for plant use. The remaining water is held by the soil particles with sufficient strength to prevent its removal by plants. The forces acting on soil water, called soil suction, can be classified as those caused by the soil particles (matric forces), those caused by the solutes dissolved in the water (osmotic forces), and those caused by gravity (gravitational forces). Matric forces arise from capillary action and electrostatic interactions between the water and the soil particles. Osmotic forces depend on the number of dissolved salts in the water indirectly affecting the movement of water through the soil. The sum of the matric and osmotic forces is called the total water potential represented in bars.

In this present study the important moist states of soil are considered as moisture less or dry soil, air dried soil or hygroscopic moisture level, wiltage level, transition moisture, field capacity, saturated soil. Briefly these conditions may be defined as moisture is completely depleted from moisture less soil, Soil moisture in an air-dry soil is at hygroscopic level. Hygroscopic water is bound tightly with soil solid; this is non liquid and primarily in the vapor form not available for plants SMC at this point is called hygroscopic coefficient (-30 ~ -35 bars). Permanent wilting point (-15 bars) SMC in soil at which plants wilt and remain wilted when placed in a dry atmosphere. Field capacity (-1/3 bar) is the amount of water in a soil two or three days after a thorough wetting of its profile, in this condition there is little downward water movement. Water in soil remains tightly bound when soil wetness increases from dry to a certain level beyond to field capacity, this wetness level is known as transition moisture and free water come into existance, on further increasing the SMC additional water is not tightly bound and behave as free water [8]. Excess moisture beyond the transition level saturates the soil (0 bars)

II. METHODOLOGY

Two Samples of soil are considered for determination of real and imaginary parts dielectric constant. Both soil samples (sandy loam) are differentiated according to their textural composition as given in Table:1

Table:1

Sample:1	Sample:2
Sand = 51.51% Silt= 35.06% Clay = 13.43%	Sand = 41.96% Silt = 49.51% Clay = 8.53%

The SMC level of moisture less or dry soil is undoubtedly zero. Hygroscopic coefficient is the water content of air-dry soil, expressed as a percentage of the oven-dry weight. The hygroscopic coefficient is the maximum amount of hygroscopic water absorbed by 100 g of dry soil under standard conditions of humidity (50% relative humidity) and temperature (15°C). This tension is equal to a force of 31 atmospheres. Water at this tension is not available to plant but may be available to microorganisms. The typical values for hygroscopic moisture content in soils around 2.65 is suitable for our consideration. Wetness corresponds to wilting coefficient *Wp* and transition moisture *Wt* of two samples soil are calculated by using the Wang and Schmmgge model [9] equation (1) and (2) respectively.

$$Wp = .06774 - 0.00064 * (\%Sand) + 0.00478 * (\%Clay) \quad (1)$$

$$Wt = .49Wp + 0.165 \quad (2)$$

Field Capacity (FC) is approximated by empirical formula equation (3) given by Schmugge *et al* [10]

$$FC = 25.1 - 0.21 * (\% Sand) + 0.22 * (\% Clay) \quad (3)$$

The water saturation state of soil occurs when all of the pores, spaces, and cracks in the soil are filled with water. This means that there is no air left in the soil. SMC corresponds to this state can be estimate using texture of soil [11]. Important wet states of soils and related water holding capacity are summarized in belowTable:2

Table:2

Wet States of soil	Related Water Holding Capacity (%SMC)	
	Sample: 1	Sample: 2
Dry	0.0	0.0
Hygrospic	2.76	2.6
wiltage	9.89	8.16
Field Capacity	17.23	18.16
Transition	21.34	20.5
Saturation	43.9	42.0

The empirical model proposed by Hallikainen *et al* [6] relates the real and imaginary parts of dielectric constant ($\varepsilon' and\ \varepsilon''$ with the volumetric soil moisture content (m_v) and texture is used in present investigation. The model equation generated by curve fitting experimental data with second order polynomial expression was given by equation (4) as :

$$\varepsilon' or \varepsilon'' = (a_0 + a_1 S + a_2 C) + (b_0 + b_1 S + b_2 C) m_v + (c_0 + c_1 S + c_2 C) m_v^2 \quad (4)$$

Where S is percentage of sand and C is percentage of clay, m_v is the volumetric moisture content of the soil and a_0, a_1, a_2, b_0, b_1, b_2, c_0, c_1, and c_2 are the empirically determined coefficients for the best fit.

The empirical model of Hallikainen *et al* [6] accounts for frequency and soil texture. The equation (4) is applicable to dielectric data collected at frequencies 1.4 GHz, to 18.0 GHz, depending on the values of the parameters used. The values of empirical coefficients a_0, a_1, a_2, b_0, b_1, b_2, c_0, c_1, and c_2 for determination of ε' and ε'' at frequencies 10.0, GHz are given as:

Table:3 Hallikainen coefficients for determination of ε' and ε'' at 10.0 GHz

	a_0	a_1	a_2	b_0	b_1	b_2	c_0	c_1	c_2
ε'	2.502	-0.003	-0.003	10.101	0.221	-0.004	77.482	-0.061	-0.135
ε''	-0.07	0.0	0.001	6.62	0.015	-0.081	21.578	-0.061	0.332

Using the values of above Hallikainen coefficients for and volumetric moisture (m_v) corresponds to water holding capacity of different moist states of two soil samples, values of ε' and ε'' are estimated at 10.0 GHz.

III. RESULTS AND DISCUSSIONS

The calculated values of volumetric % SMC by model equations for both soil samples corresponds to different water holding states as given in table-2 and respective values of real part and imaginary part of dielectric constant calculated by empirical model equation (4) are plotted in below figure-1 and 2 for sample-1 and sample-2 respectively.

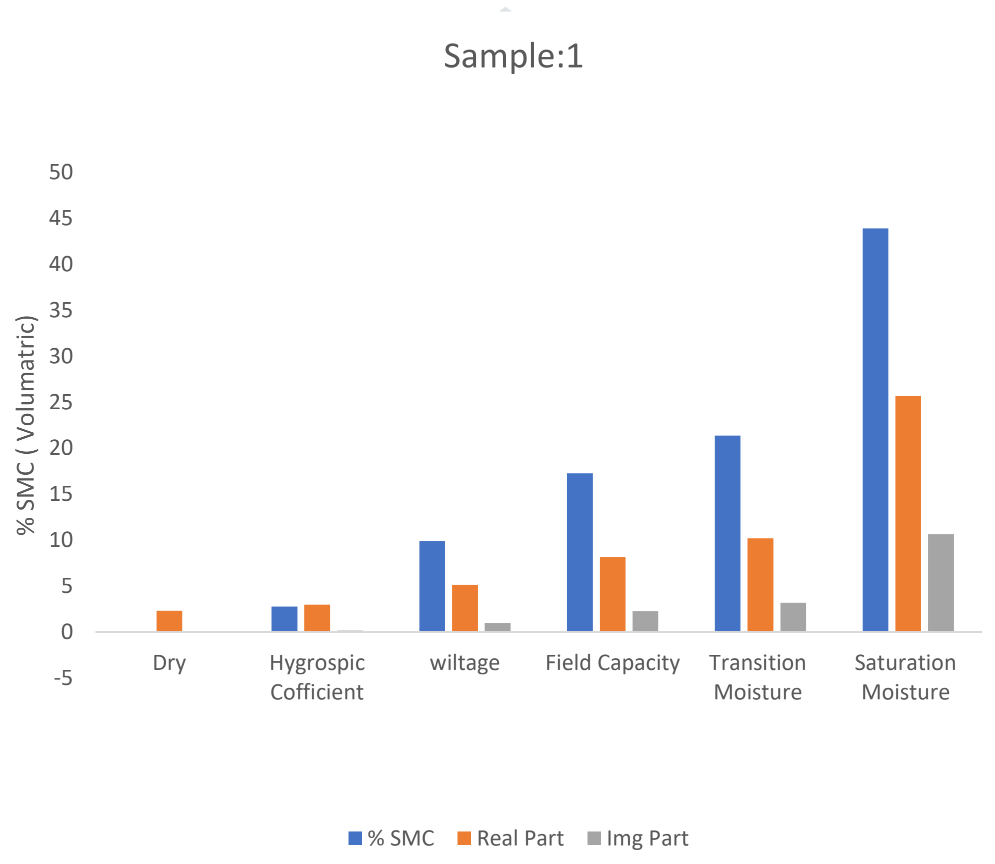

Fig-1, Variations of Real and Imaginary part of dielectric constant corresponds to moist states of soil v/s Vol. SMC (Sample :1)

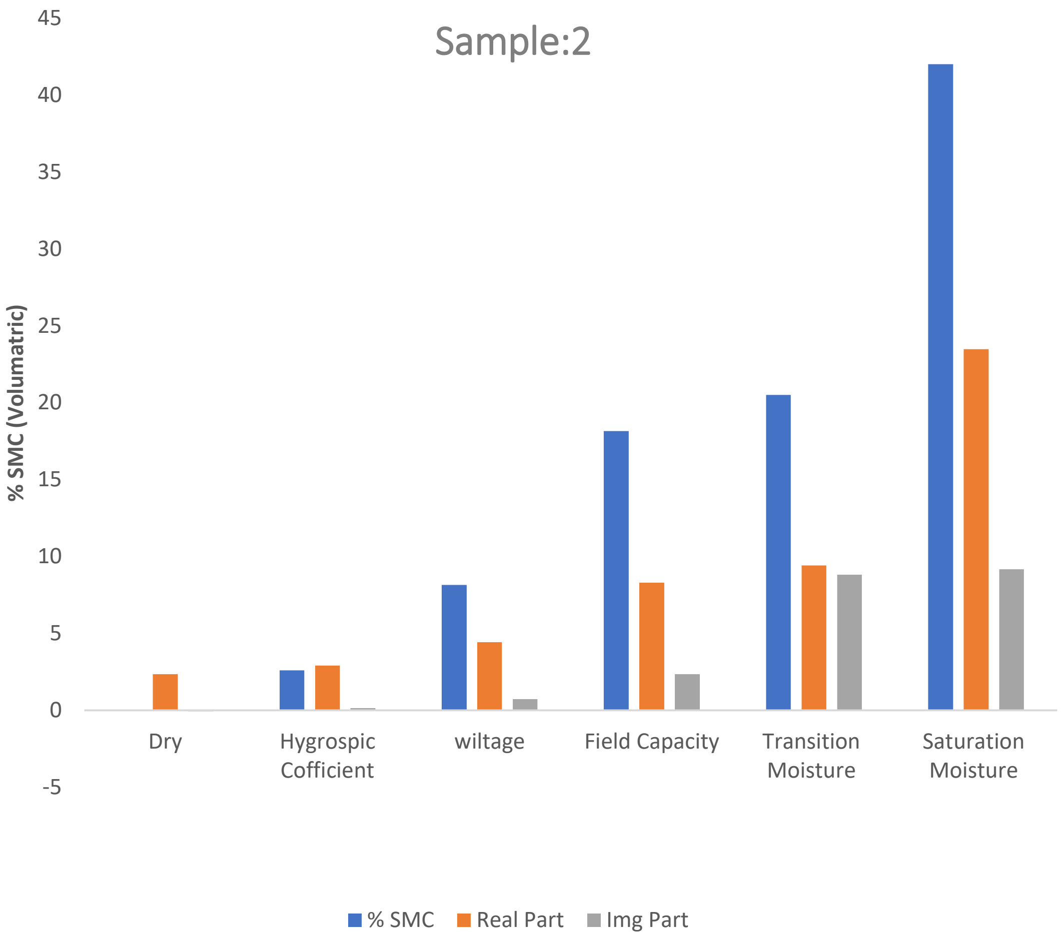

Fig-2, Variations of Real and Imaginary part of dielectric constant corresponds to moist states of soil v/s Vol. SMC (Sample :2)

It is evident from above Fig-1 1nd Fig-2, The first group of columns (SMC not visible because soil is dry) corresponds to moisture less soil (SMC=0.0%). Second group of columns of both figures correspond to air dry soil or hygroscopic coefficient (SMC=2.76% & 2.60% for sample 1&2), here slightly increased moisture is held very tightly bound mostly by the soil colloids. Third group of columns corresponds to further increase in wetness (SMC=9.89% & 8.16% for sample 1&2). This is the state of tightly bound water molecules, here plants still not able to absorb adequate water for survival and this is corresponding to the permanent wiltage condition. If SMC level further rises up, then water is soon draining out from larger or macro pores and soil is said to be at the Field Capacity level (SMC=17.23% & 18.16% for sample 1&2) shown by forth group of column. At higher levels moistness (SMC=21.34% & 20.50 % for sample 1&2) water not remains bound at transition level of moisture as shown by fifth group of columns. After transition moisture state plenty of water available as free water contribute to high values of real and imaginary parts of dielectric constant. Last sixth group of columns of figure-1 and figure-2 corresponds to situation when sample is completely saturated (SMC=43.90% & 42.0% for sample 1&2) with moisture; all pores (macro and micro) are filled by water. Here, dielectric constant of mixture is largely due to dielectric constant of water. Figure-1 and figure-2 also shows the relationship between the real and imaginary parts of the dielectric constant and volumetric soil moisture content. The high dielectric constant of water significantly increases both the real and imaginary parts of the dielectric constant of the soil as the volume fraction of water in the soil increases. Rate of increasing of real part of dielectric constant is more when moisture level of soil is above the transition level.

IV. CONCLUSIONS

Values of real and imaginary part of dielectric constant increases non-linearly with increasing SMC because water added to dry soil were held more tightly by the soil particles and had the dielectric properties of frozen water or bound water. Water in moist soil can be classified as free water and bound water. The free-water molecules have dielectric properties similar to those of normal liquid water, while bound water tightly bound to the soil particles interacts with the surfaces of soil minerals has different properties from free water. Its structure is more distorted compared to the structure of free water. Bound water reportedly has higher specific volume, viscosity, density, freezing temperature and specific heat, lower dielectric constant, and greater resistance to molecular rearrangement than free water. These effects extend for very short distances, on the order of three to ten molecular water layers. Hydrogen bonding and Van der Waals forces (of intermolecular attraction) are cited as the reasons for the bonding of water to soil surfaces. Recent research has also shown that the dielectric properties of soil depend on the amount of "bound water" which is in close contact with minerals in the soil.

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