Chapter V

Soil water content
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5.1 Introduction

In microwave remote sensing, for the study of dry and wet soils, and in microwave remote sensing of soil moisture, both active and passive, the dielectric permittivity is the most important parameter. Various percentages of soil-water mixtures give rise to a large dielectric permittivity variation. Hence thorough knowledge of dielectric properties of different types of soils is necessary for efficient use of microwave sensing technique for soil moisture estimation. The basis for microwave remote sensing of soil moisture is strong dependence on its moisture content due to the large contrast between the dielectric permittivity of water (80) and that of dry soil (3 to 5). The dependence of soil dielectric properties on moisture can be observed with either passive or active microwave sensors through its effect on the soils emissivity and reflectivity. Emissivity is the important parameter, which provides information about soil. All the natural objects such as soil with temperature 0 °C absolute are capable of emission, absorption and transmission. The emitted radiation from soil depends upon its dielectric permittivity, surface roughness, chemical composition, physical temperature, frequency polarization, and angle of observation. The dielectric permittivity of soil varies with the amount of moisture content present in the soil. The emissivity of the soil also varies with different moisture contents. The knowledge of the emissivity of the soil is useful for the efficient use of soil [1-3]. The dielectric properties of soil
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dependence on the presence of water content, texture, minerals, temperature, and organic matters present in it.

The measurement of dielectric properties of several agriculture, environmental, and food processes is need for the society. Microwave measurements and dielectric properties of materials are finding increasing applications, as new Electro-technology is adapted for the use in the agriculture and food processing industries. The interest in dielectric properties of materials has historically been associated with the design of electrical equipment, where various dielectrics are used for insulating conductor and other components of electrical equipment. The measurement of dielectric properties is not an end unto itself. Rather, these properties are intermediary vehicle for understanding, explaining, and empirically rating certain physical-chemical properties of materials.

Knowledge of water content in soil is fundamental requirement in many applications in the field of agricultural, forestry, hydrology, and civil engineering. This needs measurements in the laboratory and also sometimes continuous field monitoring at several depths and in different locations. Knowledge of dielectric properties of soils is also required for the improved interpretation of data from methods such as ground penetrating radar and microwave remote sensing. In order to model a complex material such as soil it is required that the dielectric permittivity of all phases be known. The permittivity of air and water are well documented, however, the permittivity of soil minerals is often estimated and their permittivity essentially remains a fitting parameter in many models. In this work we reported the dielectric permittivity and its related moisture content three soil samples. The permittivity
and loss has been measured for a single microwave frequency i.e. at 7 GHz. Soils dielectric permittivity is widely used to estimate water content in soil from remote sensing data and from in situ soil sensors such as time domain reflectometry. The dielectric permittivity of the soil mineral phase, for modeling purpose is assumed in most cases to be 5, a value based on the further assumption that soils are predominantly quartz. However, micaceous clays have been found to have permittivity values around 6, and calcite a major constituent of some soil, is known to have a permittivity nearly twice that of quartz.

There are two different techniques to measure the soil water content i.e. the direct and indirect methods. Direct measurement method involves the removal of the soil water by evaporation, leaching, or a chemical process and subsequent determination of the amount removed. Direct measurements are beset with problems principally due to the necessity for destructive sampling. Measurements cannot be repeated on the same sample of soil; hence replicate samples must be taken from a plot at any one time to determine the variance of the measurements at that time and so to permit the analyst to ascertain whether they differ significantly from determinations on other occasions. The need for replication can result in the handling of very large number of samples. Practical difficulties are compounded if determinations deep in the profile are required. Further more repeated sampling within the same area may well cause unacceptable damage to a crop or soil.

Indirect methods (nondestructive methods) like Time domain, frequency domain transmission line depend on monitoring of some soil property, which is dependent on water content. One of the important methods is based on measurement of dielectric properties of soils. In these methods,
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instrumentations are placed in or on the soil or mounting some sensors on a platform on the surface of soil. Although these methods require calibration to determine water content, they have the advantage that measurements in situ are possible, and these can be repeated in the same positions at various times. There are several techniques to measure the dielectric properties of different materials [4].

At microwave frequencies (generally about 1GHz and higher), transmission line waveguide, coaxial line, resonant cavity, and free space techniques are commonly used. The experimental techniques of the dielectric measurements can be categorized as reflection or transmission types using resonant or non-resonant systems, with open or closed structures for sensing the material samples [5].

Transmission line techniques are not cumbersome because they do not require special sample preparation. The dielectric properties can be measured easily by this technique with the use of slotted line and standing wave indicator [6]. The transmission line techniques are suitable for inhomogeneous dielectric materials. In addition, they may be easily implemented in industrial applications for continuous monitoring and control. These transmission line techniques are more sensitive and accurate. At microwave frequencies, the effect of ionic conductivity gets negligible as compared to dielectric losses [7].
5.2 Different methods for soil water content measurements

Basically there are two types of methods to determine soil water content. These are direct and indirect methods, which are described below.

5.2.1 Direct methods

i) Therogravimetric method

This method is very straightforward. A soil sample is placed in a heat-proof dish of known weight, weighted, dried in an oven set at a temperature of 100 - 110°C, removed and allowed to cool in a desiccator, then reweighed. This procedure is repeated until the sample attains a constant weight. The water content \( w \) of the sample is the mass of the water per unit mass of the dry soil

\[
W = \frac{\text{Mass of wet soil} - \text{Mass of dry soil}}{\text{Mass of dry soil}}
\]

A good oven, which is ventilated and distributes the heat evenly, is required. It should not be overloaded. The efficiency of the oven can be checked by loading it with sub samples of one mixed soil sample and then checked the variation in the water content measured.

ii) Neutron method:

In this method for water content measurement makes use of the ability of hydrogen to slow down fast neutrons, emitted from the radioactive source, much more efficiently than other substances. The source and a slow neutron detector is normally housed on one unit a "probe" which is lowered down a tube known as "access tube" inserted in the soil. Some neutron meters are designed for use on the soil surface and are constructed to a different design. Fast neutrons are moderated upon collision with atomic nuclei, in particular hydrogen nuclei. Most of the hydrogen is present in the water molecules;
changes in hydrogen concentration occur therefore, mainly as a result of changes in water content. Thus a probe is used in a soil, the number of fast neutrons that are slowed close to the source and the detector, and so detected, increase with an increase in water content. The number of slow neutrons is recorded as a “count rate,” which is read by the user from a display or may be stored in memory, which is interrogated latter with computer. The count rate is converted to water content by use of a soil-specific calibration relationship. For measurements of depth, access tubes are usually installed semi permanently. Within each, readings are taken at successive depths by lowering the probe down the access tube. Although measurements are most often made to about 1.5 m depth, they can be easily conducted at much greater depths in many soils, once the effort of access tube installation has been completed.

5.2.2 Indirect methods

i) Capacitance and TDR methods

In both the methods for soil water content determination depends on measurement of dielectric permittivity of the soil. The Dielectric permittivity of the water is about 80 and that of most soil materials is in between 3 to 5, so the dielectric permittivity of the moist soil is the sensitive measure of the volumetric content. The type of the soil influences both the methods to some extent by the dielectric permittivity of the soil matrix components.

The capacitance method includes the moist soil as a part of the dielectric of the capacitor. Measurement of the capacitor gives the dielectric permittivity, hence the water content of the soil. A variety of capacitor, parallel rods, and parallel knife blades will be used. The electrodes comprise part of a probe insertion into an access tube in the soil, and then the soil surrounding the probe
occupies the fringe field of the capacitor. In this case the system must be designed to minimize unpredictable and the variable air gaps between the access tube and the soil, yet avoid undue disturbance and compression of the soil.

ii) Time domain reflectometry technique

For measurement of soil water content is relatively new and is only beginning to gain acceptance as a routine technique, although it is a little better established than the capacitance probe method. It is an alternative method for measuring the dielectric permittivity of the soil. The principle of the method is that a high frequency electromagnetic pulse is fed into the soil between two metal rods. Part of the pulse is reflected back up through the soil from the bottom of the rods, and the time interval of the incident and reflected pulses is measured.

5.3 Methods based on measurement of the dielectric permittivity of soil

Both the capacitance and the time domain reflectometry (TDR) method for soil water content determination depend on measurement of the dielectric permittivity of water of the soil. The dielectric permittivity of water is about 80 and that of most soil material is between 3 and 5, so the dielectric permittivity of moist soil is a sensitive measure of the volumetric water constant. The type of soil influences both methods to some extent by the dielectric permittivity of the soil matrix component, hence.
For example, at a water constant of 20%, a change in the Dielectric permittivity of the soil matrix from 3 to 5 is equivalent to change in water content from 20% to 21.5%.

A practical definition of the dielectric permittivity of a material is the ratio of the value of a capacitor with the material between the plates, compared with the value of with air between the plates. A dielectric material is an insulator, as distinct from a metal, which is and conductor. Under the influence of an electric field, the positive and negative charge in a dielectric material are displaced with respect to each as other and tiny electric field, and the dielectric medium as a whole becomes polarized. The dielectric permittivity as defined above turns out to be a measure of the polarization: as a consequence, a material whose
molecules have a permanent dipole moment and are free to align with the
electric field has a very large dielectric permittivity.

The dipoles can arise from a number of physical mechanisms [19], many
of which are present in moist soil, which is a composite material with varying
proportions of air, water, and mineral material. The behavior of dielectric
permittivity for wet soil is correspondingly complex (fig. 5.3.1).

At low frequencies all electric dipoles respond to the frequency of the
applied electric field and value of dielectric permittivity 100 or 1000 or even
higher have been reported for soil [22]. These extreme values are due to
interfacial polarization, with dipoles created from induced charges on the
surfaces of air voids in the soil. Such values for K reflect the proportion and
configuration of air voids present rather than the proportion of soil water.

Above about 30 MHz these relatively microscopic dipoles can no longer
follow the field reversals and they cease to contribute to the dielectric
permittivity, which drops to the value determine by the proportion of water, air,
and soil. This value is dominated by the permanent dipole movement of the
water molecule and underlines the high sensitively to the proportion of water
present.

At sufficiently high frequencies, of the order of 3000 MHz, the water
dipole falls to follow the field’s reversal and the dielectric permittivity still
further, ultimately approaching near unity at frequencies in the optical region.
5.4 Experimental procedure to determine dielectric properties and soil water content

The experimental technique used to measure the Dielectric permittivity and water content is that of Roberts and Von Hipple [10] and fixed frequency method of Gopal Krishna [11]. A least squares fit programme of Sobhanaderi [12] is used to calculate the Dielectric permittivity. A J-band microwave transmission line waveguide setup is used for this purpose. The dielectric permittivity of soil has been measured at fixed frequency of 7-GHz and at room temperature. The soil samples were collected at Fattepure, Sendra and Karmad, which are 30 km away from Aurangabad city. The samples were collected from these areas to determine the water content and its physical and chemical properties. These samples were collected from these non-irrigated farming lands in hot summer with negligible water content, called as dry soil. These soil samples are the mixture of sand, silt and clay with very high percentage of clay. The soil sample under measurement of known volume was placed in the empty solid dielectric cell, and well pressed by a laboratory developed mechanical system to remove the air and discontinuities in the sample. The solid cell with sample was connected to the opposite end of the source of microwave bench set up. The signal generated from the microwave source was allowed to incident on the soil sample. The soil sample reflects part of the incident signal through the soil from its front surface. The values of power at different points of standing waves have been measured as a function of probe position. About (80 –100) points were recorded for a single standing wave pattern. The least squares fit has been used to determine the values of \( \lambda_0, \lambda_c, \alpha \) and \( \beta \) for the sample.
Firstly, energizing the microwave transmission line the standing wave pattern was recorded for empty cell. The soil under measurement was placed in the cell pressed it, and connecting it to the other end of the microwave bench setup. The measurements were done for three different lengths of the collected soil. The same procedure is applied for other soil samples also. Fitting these standing wave patterns of dry soil samples into the least squares fit programme, the dielectric permittivity was determined. From measured value of dielectric permittivity of dry soil, the water content has been determined, by assuming a “dry” soil sample still contain an unknown and unspecified amount of water (hygroscopic and crystal-bound water) [13]. Then standing wave patterns of above mentioned soil samples were recorded with adding volumetric water content. The standing wave patterns of these three soil samples are shown in Figures 5.5.1, 5.6.1 and 5.7.1. Fitting these standing wave patterns in the least squares fit programme the dielectric permittivity has been measured. From this dielectric permittivity, the water content in soil has been determined. The measured values of dielectric permittivity and water content are given in Tables in 5.5.1, 5.6.1 and 5.7.1
5.5 Determination of water content of Fattepure soil

Soil sample was collected from Fattepure, which is 20 to 30 Km away from Aurangabad city. The experimental observations are needed at 7GHz frequency and at room temperature, by using microwave J-band. The variation in dielectric permittivity with increasing volume of water content in this soil sample is given in the Table 5.5.1.

**Table 5.5.1 Variation in dielectric permittivity and soil water content with the addition of volumetric water for the soil sample at Fattepure at 7-GHz frequency**

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Volumetric water content (θ)</th>
<th>Dielectric permittivity (ε′)</th>
<th>Percentage change in soil water content. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>3.85</td>
<td>20.00</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>4.90</td>
<td>25.45</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>7.54</td>
<td>39.16</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>8.69</td>
<td>45.14</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>9.32</td>
<td>48.41</td>
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<tr>
<td>5</td>
<td>1.0</td>
<td>9.77</td>
<td>50.75</td>
</tr>
<tr>
<td>6</td>
<td>1.2</td>
<td>9.69</td>
<td>50.33</td>
</tr>
<tr>
<td>7</td>
<td>1.4</td>
<td>9.57</td>
<td>49.71</td>
</tr>
<tr>
<td>8</td>
<td>1.6</td>
<td>9.49</td>
<td>49.29</td>
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</tbody>
</table>
5.6 Determination of water content of Sendra soil

Soil sample was collected from Shendra, which is 20 to 30 Km away from Aurangabad city. The experimental observations are needed at 7GHz frequency and at room temperature. By using microwave J-band. The variation in Dielectric permittivity with increasing volume of water content in this soil sample is given in the Table 5.6.1.
Table 5.6.1 Variation in Dielectric permittivity and soil water content with addition of volumetric water for the soil sample at Sendra at 7-GHz frequency.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Volumetric water content (θ)</th>
<th>Dielectric permittivity (ε′)</th>
<th>Percentage change in soil water content. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>3.50</td>
<td>20.00</td>
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<tr>
<td>1</td>
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<td>3.80</td>
<td>21.71</td>
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<td>4.56</td>
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<tr>
<td>3</td>
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<td>39.88</td>
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<td>4</td>
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<td>8.80</td>
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<td>9.87</td>
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<td>6</td>
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<td>9.81</td>
<td>56.05</td>
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<tr>
<td>7</td>
<td>1.4</td>
<td>9.76</td>
<td>55.77</td>
</tr>
<tr>
<td>8</td>
<td>1.6</td>
<td>9.72</td>
<td>55.54</td>
</tr>
</tbody>
</table>
Figure 5.6.1. Standing wave pattern of Soil sample at Sendra with increasing concentration of water.

5.7 Determination of water content of Karmad Soil

Soil sample was collected from Karmad, which is 20 to 30 Km away from Aurangabad city. The experimental observations are needed at 7GHz frequency and at room temperature. By using microwave J-band. The variation in dielectric permittivity with increasing volume of water content in this soil sample is given in the Table 5.7.1.
Table 5.7.1 Variation in dielectric permittivity and soil water content with the addition of volumetric water for the soil sample at Karmad at 7-GHz frequency.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Volumetric water content (θ)</th>
<th>Dielectric permittivity ($ε'$)</th>
<th>Percentage change in soil water content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>3.51</td>
<td>20.00</td>
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<td>1</td>
<td>0.2</td>
<td>5.10</td>
<td>29.05</td>
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<td>0.4</td>
<td>5.44</td>
<td>30.99</td>
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<tr>
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<td>5.74</td>
<td>32.70</td>
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<td>33.39</td>
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<td>5</td>
<td>1.0</td>
<td>6.11</td>
<td>34.81</td>
</tr>
<tr>
<td>6</td>
<td>1.2</td>
<td>5.94</td>
<td>33.84</td>
</tr>
<tr>
<td>7</td>
<td>1.4</td>
<td>5.85</td>
<td>33.33</td>
</tr>
<tr>
<td>8</td>
<td>1.6</td>
<td>5.78</td>
<td>32.93</td>
</tr>
</tbody>
</table>

Figure 5.7.1. Standing wave pattern of Soil sample at Karmad with increasing concentration of water.
Figure 5.7.2. Variation of dielectric constant of soil with volumetric water content.

![Graph showing variation of dielectric constant with volumetric water content.]

Figure 5.7.3. Variation in volumetric soil water content with addition of water.

![Graph showing variation in volumetric soil water content with addition of water.]

5.8 Conclusion

From Tables 5.5.1, 5.6.1 and 5.7.1 it is observed that, there is increase in dielectric permittivity and soil water content with addition of water, and this variation is slow at lower volumetric water content range. The variation in dielectric permittivity with increasing volumetric water content for the three samples is shown in Figure 5.7.2. This increase may be due to the addition of high dielectric permittivity liquid (water) to the soils. At this lower range of water content addition of water to the soil has a little effect on soil, as the water becomes bounded with the soil. Due to this increase in soil moisture there is small increase in dielectric permittivity. The variation in dielectric permittivity and soil water content with increasing volumetric water at this lower range is very similar to the work as reported by J. Behari [14] and Vyas et al. [15] and Srivastava et al [16].

From Tables 5.5.1, 5.6.1 and 5.7.1 it can be seen that, there is continuous increase in dielectric permittivity with increase in water content up to 1.0 %, and this increase is faster than that of lower range. This may be due to higher value of dielectric permittivity of water. Due to increase in water content some of the soil is replaced with water. The water content will also be increased. Due to more presence of this high dielectric permittivity liquid at this range there is fast increase in Dielectric permittivity and water content. It is observed that the water (moisture) content increases faster after 6 to 8 %. This is in agreement with the earlier investigation of Dunlop and Makower [17, 18].

From Tables 5.5.1, 5.6.1 and 5.7.1 it has also been observed that, after 1% of water content there is decrease in dielectric permittivity and water content. The reason may be, with further increase in water content (above 1%)
the total water content into soil is more or the soil gets saturated. At this saturation point of water into soil the chemicals, minerals, organic matters, and water-soluble compounds from soil will get dissolved in it. The water present in soil along with these factors forms an electrolyte solution of higher concentration. According to the theory of electrolyte solution, the dielectric permittivity of solutions (liquids) decreases at higher (strong) concentration of electrolyte solution. Due to this reason there may be decrease in dielectric permittivity, when water content is more than 1%. This is in agreement with the earlier investigations of electrolyte solutions by Hasted [19]. The variations in soil water content with increasing volumetric water content for the three soil samples is shown in Figure 5.7.3.

From Tables 5.5.1, 5.6.1 and 5.7.1 it has been also observed that the variation in dielectric permittivity and water content is different, though the addition of water to the three soil samples is equal. The variation in dielectric permittivity and water content is higher in samples at Fattepure and Sendra than that of sample at Karmad. This may be due to more presence of chemical compounds, organic matters, minerals, and water-soluble salts in samples at Fattepure and Sendra than that of Karmad. Another reason may be the clay present in soil samples at Fattepure and Sendra may be more than that of Karmad. According to M T Hallikainen [20] the soil texture shown to have an effect on dielectric behavior of soil that is moisture retentive capacity of clayey soil is more than that of sandy soil [21]. Due to these reason the dielectric permittivity and water content may be higher in samples at Fattepure and Sendra than that of Karmad.
From this work, it is clear that it is possible to determine water content in soil using dielectric method. The values of dielectric permittivity are not only sensitive to water content, but also sensitive to texture of soils.
References


