Variability of dielectric constant of dry soil with its physical constituents at microwave frequencies and validation of the CVCG model

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In the design of active and passive sensors for microwave remote sensing of soil, its electrical parameters like scattering coefficient and emissivity play a vital role. One of the important parameters on which these two depend is the value of the dielectric constant that again varies with the physical constituents of the soil. In this paper, an attempt has been made to study the variability of the dielectric constant of dry soil with its physical constituents. The soil samples are taken from different parts of northern India and variations of dielectric constant as observed in the X-band are presented here. The CVCG model, generated to compute the dielectric constant for dry soil from its physical constituents has also been validated.

Keywords: Dielectric constant, Soil, CVCG model, Sensors, Remote sensing, Microwave remote sensing

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1 Introduction

The properties of dry soil along with its type have a great importance in agriculture. The soil has physical as well as electrical properties. Colour, texture, grain size, etc. comprise the physical properties while, the electrical properties include dielectric constant, conductivity and permeability. For microwave remote sensing, out of these three, dielectric constant is the primary important electrical property for dry soil. From the measured value of dielectric constant, one can estimate the emissivity and scattering coefficient of the soil. The passive microwave remote sensing sensors respond to the emissivity of the soil whereas scattering coefficient is used to design active microwave remote sensing sensors. However, due to the dependence of dielectric constant on the physical constituents of the soil, the study of its variability with physical constituents of the soil is required for the detailed study of the soil using microwave remote sensing techniques. For making an estimation of the dielectric constant using only the values of the physical constituents of the soil, a model has already been generated named Calla Vivek Chetan Gangadhar (CVCG) model.

2 Soil

Soils are composed of solids, liquids and gases mixed together in variable proportions. The relative amounts of air and water present depend upon the way the soil particles are packed together. The form of packing is different for different structures. The size of the particles determines the soil texture and way of arrangement of the particles determine its structure. Physical properties, which can be evaluated by visual inspection or by feel, are measured on some kind of scale such as size, strength or density.

Soil is characterized by sand, silt and clay. Each soil has its own set of constituents depending upon its origin, nature, location, etc. The soil is differently named depending on the percentage of each constituent.

In this present paper, is presented the results of a study carried out with 13 different soil samples collected from various locations of northern India, viz. Assam and Meghalaya in the east, Rajasthan in the west, Kashmir in the north, and UP in central India. The colour and physical constituents of the soil samples are shown in Table I along with their wilting coefficients (W). The value of W is calculated by using the Wang and Schmugge model with the following formula:

\[ W = 0.06774 - 0.00064 \times (\text{sand } \%) + 0.0478 \times (\text{clay } \%) \]

Normally the dielectric constant of dry soil is independent of frequency, but in these measurements,
some variability is observed due to the presence of small quantity of moisture in the soil which enters in the soil while handling the soil during measurement. Due to the variation of \( \varepsilon_r \) with frequency, the study is carried out for values calculated at a common (approximate) frequency. The values of the dielectric constants of the soil samples at those frequencies are also presented in the Table I.

### 3 Methods of measurement

There are different methods\(^5\) available for measurement of dielectric constant of dry soil at microwave frequencies, viz.

(a) Waveguide cell method  
(b) Resonant cavity method  
(c) Network analyzer method

The choice of a method depends upon a number of factors such as shape and size of the available samples, methodology of controlling the effects of temperature, humidity, etc.

In the present study, the waveguide cell method\(^5\) has been adopted.

### 4 Results and discussion

The graphs of the variation of the dielectric constant as given in Table I for Assam, Rajasthan and Kashmir soil samples with the percentage of physical constituents are presented in Figs 1-3. A linear trend line is drawn to show the variations. The graphs for Meghalaya and UP soil sample are not drawn due to non-availability of more than one soil sample from those states.

Figure 1 depicts the variations of \( \varepsilon_r \) with the % of sand for (a) Assam, (b) Rajasthan and (c) Kashmir.

![](image-url)
soil samples, respectively. The observations made from these figures are as follows:

(i) For soils of Assam the value of \( \varepsilon_r \) increases with an increase in the sand percentage with a slope of 0.01 as presented in Fig. 1(a).

(ii) It is observed that the trend of variation of \( \varepsilon_r \) in case of soils from the deserts of Rajasthan is inverse to that from soils from Assam, i.e., the value of the dielectric constant decreases with the increase in the percentage of sand. The slope here is -0.00075. Thus, the slope is very small as compared to that of the dry soil samples of Assam as presented in Fig. 1(b).

(iii) The variation of dielectric constant with % of sand for soil samples of Kashmir is similar to the trend followed by the Rajasthan soil samples; however, the slope in this case is much more. It is found that the slope is -0.01375 as presented in Fig. 1(c).

Thus, it can be seen that the variation of \( \varepsilon_r \) with respect to % of sand is highest in case of Kashmir soils and lowest in case of Rajasthan soils.

The variations of \( \varepsilon_r \) with the % of silt for the soil samples are shown in Fig. 2. From the graph in Fig. 2, one sees that:

(i) The variation of \( \varepsilon_r \) with respect to % of silt for the soil samples of Assam has a decreasing trend, that is, the value of \( \varepsilon_r \) decreases with the increase of % of silt. The slope is found to be -0.01923 as presented in Fig. 2(a).

(ii) The trend of Rajasthan soil samples has increasing nature with a slope of 0.000795 as presented in Fig. 2(b).

(iii) The soil samples from Kashmir shows a similar trend with that of Rajasthan, i.e., an increasing trend. However, the slope in case of Kashmir is much more than that for the soils of Rajasthan and is equal to 0.0159 as presented in Fig. 3(b).

Thus, slope in this case is found to be maximum for Kashmir again, while Rajasthan soil samples still show the least variations in their values of \( \varepsilon_r \).

Figure 3 presents the variation of \( \varepsilon_r \) with % of clay. One can draw the following inputs from the graph:

(i) The value of \( \varepsilon_r \) for the soil samples of Assam is almost independent of the % of clay with a nearly zero slope as presented in Fig. 3(a).

(ii) The Rajastan soils follow an increasing trend. The slope for them is 0.0014 as presented in Fig. 3(b).

(iii) Same increasing trend like Rajasthan soils is obtained in case of the Kashmir soil samples, but their slopes vary. The slope for the Kashmir soils is 0.0425, that is much less than that of soils of Rajasthan as presented in Fig. 3(c).

So, it is evident that the dielectric constant values for Assam soils do not show any variation with % of clay. However, the variation of \( \varepsilon_r \) with respect to % clay is found to be the highest for soil samples from the Kashmir Valley.
Validation of CVCG model

Based on the values of the dielectric constants of the four soil samples of Rajasthan measured at eight different frequencies, the CVCG model has been generated. It uses only the percentage of physical constituents to estimate the value of the dielectric constant of a soil. It has been already validated by using the UP soil. Here the experimentally measured values of \( \varepsilon_r \) for the soil samples of Assam, Meghalaya and Kashmir are compared with the values obtained using the CVCG model.

Tables 2 and 3 present a comparison between the experimentally measured values of the \( \varepsilon_r \), along with the % errors. The values of \( \varepsilon_r \), are taken at an approximately equal frequency.

Using the CVCG model and known physical constituents of soils of Assam, Meghalaya and Kashmir, the \( \varepsilon_r \) values at different frequencies were estimated. The estimated values of \( \varepsilon_r \) were then compared with the experimentally measured values of \( \varepsilon_r \) of these soils. The % variations between the estimated and measured values of \( \varepsilon_r \) were then determined. These are presented in Tables 2 and 3.

From Table 2, one observes that for Assam soils the maximum variation is -36.76% and the minimum variation is -2.73%. From Table 2 for Assam soil, the % variations of 36.76% and 24.32% are two points that can be neglected in the overall scenario of 15 points which leaves the total range of variation from -13.31% to +17.75% which is within 20% of the experimentally measured value of \( \varepsilon_r \).

Another set of dry soil samples that were used for validation of CVCG model was from Kashmir. Here the physical constituents of Kashmir soil were used along with CVCG model to estimate the dielectric constant of these soils. After estimation of \( \varepsilon_r \), the
Table 3—Comparison between experimental and calculated values of $\varepsilon_r$, for Kashmir (K) soils

<table>
<thead>
<tr>
<th>Sample</th>
<th>Measured Value</th>
<th>Estimated Value</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>2.385</td>
<td>2.7218</td>
<td>+2.89</td>
</tr>
<tr>
<td>K2</td>
<td>1.995</td>
<td>2.7613</td>
<td>+27.75</td>
</tr>
<tr>
<td>K3</td>
<td>2.385</td>
<td>2.719</td>
<td>+12.28</td>
</tr>
</tbody>
</table>

(b) Measurements made at 8.875GHz

<table>
<thead>
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<th>Sample</th>
<th>Measured Value</th>
<th>Estimated Value</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>2.325</td>
<td>2.005</td>
<td>-15.97</td>
</tr>
<tr>
<td>K2</td>
<td>1.935</td>
<td>2.1528</td>
<td>+10.12</td>
</tr>
<tr>
<td>K3</td>
<td>2.195</td>
<td>2.1333</td>
<td>+2.89</td>
</tr>
</tbody>
</table>

(c) Measurements made at 9.707GHz

<table>
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<th>Measured Value</th>
<th>Estimated Value</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>2.28</td>
<td>1.7876</td>
<td>-27.54</td>
</tr>
<tr>
<td>K2</td>
<td>1.94</td>
<td>1.7995</td>
<td>-7.81</td>
</tr>
<tr>
<td>K3</td>
<td>2.0467</td>
<td>1.8717</td>
<td>-9.35</td>
</tr>
</tbody>
</table>

values so obtained were compared with the experimentally measured values of $\varepsilon_r$. These two values were compared and the % error in estimation of $\varepsilon_r$ using CVCG model calculated. The comparison is given in Table 3. From Table 3 one can see that the variation in the $\varepsilon_r$, like $+27.75\%$ and $-27.54\%$ are the values that occur once in 12 values and so they can be neglected for the present discussion. The overall % variation lies between $-15.9\%$ to $+12.37\%$. These limiting values are close to the range of variables that is expected from the waveguide cell method.

6 Conclusions

From the detailed study of dielectric constant of certain soils in relation to the physical constituents, it is evident that the dielectric constant of dry soil has dependence on the physical constituents of the soil. The graphs in Figs 1-3 show the dependence of $\varepsilon_r$ on each of the physical constituents like sand, silt and clay. The different slopes obtained also give a clear indication of the effect of % of different constituents of the soils of different regions on the value of $\varepsilon_r$.

Having obtained the effect of the % of each constituent on $\varepsilon_r$, an attempt has been made to validate CVCG model that provides the simple methodology for estimation of $\varepsilon_r$ from the known % of different physical constituents.

From Tables 1-3 it is observed that, leaving aside four out of 24 values of estimated $\varepsilon_r$, one can say that the overall range of % error in $\varepsilon_r$ is within the allowable range of error that is normally encountered in the waveguide cell method.

These results are unique because the varied types of soils have been considered in this study. The soils of Kashmir, Northeast, UP and Rajasthan have been used for measurement of dielectric constant and estimation has been done for these soils using their physical constituents. This makes it unique and very useful for the scientists working in the field of microwave remote sensing for soils and also these inputs will be useful for agriculture scientists.

Thus, it gives a direction for the scientists working in the field of microwave remote sensing of terrain, it is possible for them to estimate $\varepsilon_r$ from the physical constituents within the limits of measurement error. From this estimated $\varepsilon_r$ one can estimate emissivity and scattering coefficient that will provide the tools for designing the passive and active microwave remote sensing sensors.

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References