SETSCI Conference Indexing System, Volume 3 (2018), 724-726

ISAS 2018-Winter
2nd International Symposium on Innovative Approaches in Scientific Studies
November 30 – December 2, 2018, Samsun, Turkey

A Gaussian Model for Dielectric Permittivity in Moisty Soils

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Presentation/Paper Type: Oral / Full Paper

Abstract – Complex permittivity of soil is connection with volumetric water content robustly. Especially, Dielectric constant rapidly varies with volumetric water content because of the robust connection between volumetric water content and dielectric constant, if volumetric water content is known, dielectric constant can quickly predict. If dielectric constant is known, volumetric water content can simply predict via mathematical models. Relation of dielectric constant and volumetric water content is investigated different environments with various soil textures. A Gaussian mathematical model is proposed by means of experimental data at 9.5 GHz. Proposed mathematical model is compared with different mathematical models.

Keywords *– Dielectric constant, volumetric water content, soils*

I. Introduction

Volumetric water content (θ_v) affects for agriculture and crop quality of agriculture. Slope of soil in rainy areas is crucial, because layers keep the water (volumetric water content) can cause landslide. Complex permittivity is important for electromagnetic wave signal propagation and attenuation. Because complex permittivity varies by different media, determination of complex permittivity is very difficult at the microwave frequencies. Complex permittivity is given by

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \tag{1}$$

Where ε^*, ε', ε'' are respectively complex permittivity, dielectric constant, dielectric loss factor.

Measurements of θ_v can be categorised as direct and indirect measurements. Gravimetric measurement is a direct measurement in which the value of θ_g is determined by subtracting dry from wet sample of soil weights [1].

$$\theta_g = \frac{wet\ soil - dry\ soil}{dry\ soil} \tag{2}$$

Where $\theta_g\ (g/g)$ is gravimetric water content. Besides, water content is given by volume of bulk soil.

$$\theta_v = \frac{volume\ of\ water}{volume\ of\ bulk\ soil} \tag{3}$$

Where $\theta_v\ (cm^3/cm^3)$ is volumetric water content. This method can use to calibrate other measurement methods. But it is not practical due to taking much time [2]. Various methods were used previous measurements for determining of θ ([2],[1],[3]). A method for determining of θ is measurement of dielectric permittivity (ε'). The measurements were executed and collected for mathematical model vicinity of Ahmedabad, India [4].

This work was supported by Dokuz Eylul University BAP 2018. KB.FEN.038

Proposed model based on the experimental data at 9.5 GHz. Several dielectric constant measurements are available. Very familiar dielectric constant measurements for soil environments at the microwave frequencies are time domain reflectometry (TDR), capacitance method, ground penetrating radar (GPR). Measurements of complex permittivity change with porosity bulk density, temperature, bound or free water constituents, electric dipole and polarization, percentage of air, measured frequencies. First utilized TDR method for soil measurements was reported by [5]. TDR method in dielectric constant measurements is the most popular method compared to other methods. Measurement method is given following. Firstly, length of probe is recorded. Electromagnetic signal is driven by source and transported via coaxial cable which is bound a probe. The probe is injected soil medium. Reflected signal from probe go back. Elapsed time of signal travelling from input of probe to output of probe is measured and dielectric constant is calculated following procedure.

$$vt = 2L \tag{4}$$

$$v = \frac{c}{\sqrt{\varepsilon_r'}} \tag{5}$$

Where v is electromagnetic wave speed in medium, L is probe length, t is time, c light speed ($3x10^8\ m/sn$), ε_r' is relative dielectric constant.

$$\varepsilon_r' = \left(\frac{ct}{2L}\right)^2 \tag{6}$$

Dielectric constant is also measured capacitance method. The method was used in [6] and a mathematical model proposed by Wu et al.

$$\varepsilon_r' = 33\left(\frac{1}{1+(1.5(1-\theta_v))^n}\right)^{1-(1/n)} \tag{7}$$

Where n is experimental constant, for quartz sand it is 14 with particle sizes from 0.15 to 0.9 mm.

Another model was used by Ferre et al. using TDR [7].

$$\theta_v = 0.1181\sqrt{\varepsilon_r'}\text{-}0.1841 \quad (8)$$

Top et al. was used TDR with a range of 1MHz-1GHz [5]. It is very popular since first published third degree polynomial fitting is used. Empirical measurements are supported their mathematical formulation. Their equations are given by

$$\varepsilon_r' = 3.03 + 9.3\,\theta_v + 146\,{\theta_v}^2 - 76.7{\theta_v}^3 \quad (9)$$

TDR model was used Roth et al. for relationship $\theta_v - \varepsilon_r'$ [8]. Experimental measurements were performed by Roth et al. Their mathematical model is given by

$$\theta_v = -0.072 + 0.044\varepsilon_r' - 0.0019{\varepsilon_r'}^2 + 0.00003{\varepsilon_r'}^3 \quad (10)$$

When one wants to change some factors (soil textures, measured frequency, porosity), the alteration probably breaks down all of the mathematical model for polynomial curve fitting because of not controlled standard deviation and stickiness. Proposed model is not required for a new formulation in all of the Gaussian models. It is only required to change the using of constant values related to experimental measurements. The proposed model has soft transition on the curve due to standard deviation, variance, and mean. Proposed model is given by

$$\varepsilon_r' = \eta e^{-(\frac{\theta_v-\mu}{\sigma})^2} \quad (11)$$

Where η, μ, σ are constants, and their values are $\eta = 84.12$, $\mu = 1.129$, $\sigma = 0.644$. Results of experimental is showed in the figure 1 for different soil textures at 9.5 GHz [9].

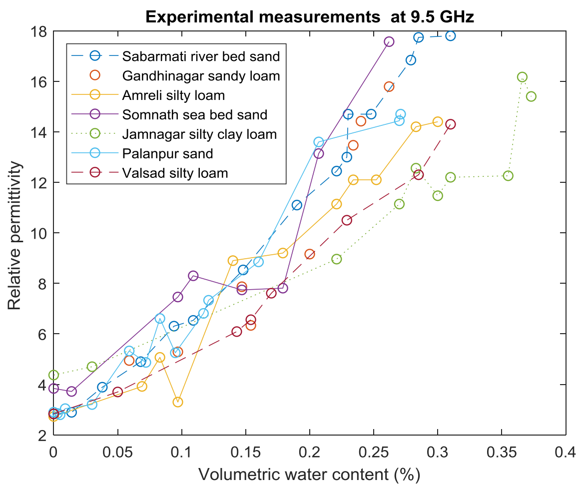

Fig. 1 Experimental measurements relative permittivity and volumetric water values for different districts at 9.5 GHz

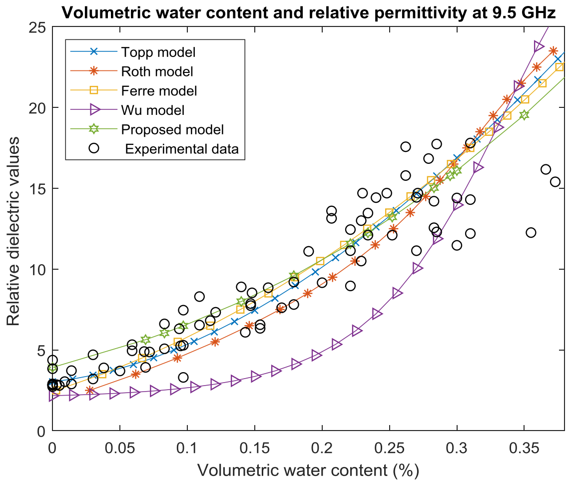

Fig. 2 Relationship between relative dielectric values and volumetric water content for both computed and measured values

II. Results

Relative dielectric constant is not linear with volumetric water content. Actually, relation between relative dielectric constant and volumetric water content are very complex. It is considered partly, small gaps of water content volumetric is linear with relative dielectric constant, but volumetric water content from 0.05 to 0.5 is not linear. Because of nonlinearity between relative permittivity and volumetric water content, Topp model and Roth model cannot achieve a good curve fitting. The models fit well in the restrained gap values of volumetric water content. If soil textures, measured frequency, porosity are changed, Topp model and Roth model is probably required to changing all the mathematical models for polynomial curve fitting. Proposed model is robust due to having standard deviation, variance and mean value. η, μ, σ are changed easily and calibrate a new Gaussian mathematical model for curve fitting. For $0.5 < \theta_v < 1$, Roth model diverges from a good curve fitting and the model slowly is broken down step by step. Topp model for $\theta_v > 0.5$ moderately is good at 9.5 GHz. Ferre model for $\theta_v > 0.7$ deteriorate slowly with increased values. Wu model is very bad of all the volumetric water content, because Wu model has not only polynomial model but also has not a linear model. Proposed model, Topp model, Ferre model and Roth model are very close to $\theta_v < 0.4$ for a good agreement among them. The close relationship is showed in figure 2. Proposed model is very close to Topp model at all the range of volumetric water content ($0 < \theta_v < 0.99$). Although Topp model has a polynomial curve, Proposed model has a Gaussian curve. But their curves amazingly are similar to each other. Both Topp model and Gaussian model are harmonious with experimental measurements in figure 2. Proposed model has maximal dielectric constant among them at the zero moisture.

III. Discussion

Investigations based on experimental consequences were formerly exhausting. Besides, the investigations consumed much time such as gravimetric measurements. Afterwards, mathematical models were discovered for fixed soil mixture and a given frequency. Some mathematical models were not accordance with experimental consequences. A few models were suitable for experimental consequences like Topp model. If one changes experiment condition, both dielectric constant and volumetric water content change. Consequently, mathematical model must be changed with proportionally experimental consequences. Topp model has fixed constants and the fixed constants changing are very difficult. Fast changing constants (η, μ, σ) were suggested with Gaussian method. They change with soil textures, moisture, frequency, temperature. They quickly are changed by new fixed values.

IV. CONCLUSION

Measurements of θ can be categorised gravimetric and volumetric. Both gravimetric and volumetric measurements were respectively given by (2), (3). Dielectric measurement techniques were investigated at the microwave frequencies. Some of the techniques were given in time domain reflectometry (TDR), capacitance method, ground penetrating radar (GPR). Measurement of dielectric constant with TDR method was explained in order. Measured data values were investigated in figure 1 [4]. A new Gaussian model is stated. Advantage of the Gaussian model was emphasized. Mathematical models are presented. The models are compared at 9.5 GHz in figure 2 for several soil textures.

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