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Effect of Water Content on Brightness Temperature and Emissivity of Soil for Passive Remote Sensing Applications

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ABSTRACT

The relative complex dielectric constant ($\boldsymbol{\varepsilon_r = \varepsilon_1 - j\varepsilon_2}$) of a number of sandy soil samples from the Markib seashore, in Libya has been measured as a function of moisture content at microwave frequency in the X-band (f=10.7 GHz, λ=2.8 cm) and L-band (f=1.4 GHz, λ=21 cm). A knowledge of the complex dielectric constant of soils is essential in the interpretation of microwave airborne radiometer data of the Earth's surface. The reflectivity and emissivity of smooth surface have been calculated in both polarizations at various nadir angles using the measured laboratory data. It has been found that the emissivity decreases at larger angles of incidence for horizontal polarization, whereas it increases at vertical polarization with increasing incidence angle to a maximum at the Brewster angle. It has also been observed that the incidence angle, at which the Brewster angle occurs, shifts toward grazing for higher percent moisture content. The brightness temperature of dry and wet soil has been computed in both horizontal and vertical polarization mode as a function of physical temperature and dielectric constant of each soil with varying moisture content. The brightness temperature of dry and wet soil depend on dielectric constant, physical properties, polarization and the angle of incidence of microwaves. These facts are especially important and can be used as diagnostic tool for water prospecting in deserts.

Keywords: Dielectric Constant, Passive Microwave Radiometer, Soil moisture Content, Brightness Temperature, Emissivity.

تأثير المحتوى المائي على درجة حرارة السطوع الانبعاثية من التربة وتطبيقها في الاستشعار عن بعد ذات النظم السلبية (غير الفعالة)

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الملخص

تم استخدام سلسلة من التجارب في هذه الدراسة التي تم التحكم بها مختبريا" باستخدام منظومة معينة لقياس ثابت العزل ($\varepsilon_r = \varepsilon_1 - j\varepsilon_2$) لعدة نماذج من التربة الرملية (من ساحل مدينة المرقب في ليبيا) كدالة لمحتوى الرطوبة عند حزمة **X** (التردد=10.7 كيكاهرتز والطول الموجي =2.8 سم) وحزمة **L** (التردد=1.4 كيكاهرتز والطول الموجي =21 سم) للموجات المايكروية. إذ تم إعداد نموذج (model) الذي يصف ويقيم منظومة التربة – الماء– الهواء، ذلك ان تركيز الماء في التربة يؤثر على خاصية ثابت العزل، معرفة ثابت العزل للتربة ضروري وأساسي إذ يساعد في تفسير بيانات مقاييس الإشعاع المايكروية عن سطح الأرض. تم حساب الانعكاسية والانبعاثية عند زوايا مختلفة (5 إلى 90 درجة) في حالة الاستقطاب العمودي والاستقطاب الأفقي وباستعمال البيانات المقاسة عن ثابت العزل. وقد وجد أن الانبعاثية تقل بازدياد زاوية السقوط بالنسبة للاستقطاب الأفقي بينما تزداد بالنسبة للاستقطاب العمودي مع زيادة درجة السقوط إلى أن تصل زاوية بروستر (Θ_m) وكذلك لوحظ أن زاوية السقوط عندما تصل زاوية بروستر تنحدر قليلا عندما تزداد الرطوبة. وتم حساب درجة حرارة السطوع لمحتوى الرطوبة للتربة لكلا الاستقطابين كدالة لدرجة الحرارة وثابت العزل للتربة لعدة درجات من الرطوبة. درجة حرارة السطوع للتربة الجافة والرطبة تعتمد على الخواص الفيزيائية (ثابت العزل، الاستقطاب، وزاوية السقوط للموجات المايكروويية). هذه الحقائق الأساسية مهمة جدا ويمكن اعتبارها كأجهزة تشخيصية للتنقيب عن أماكن وجود الماء في الصحراء.

الكلمات الدالة: ثابت العزل للتربة، حرارة السطوع، الانبعاثية، الموجات المايكرويه، التحسس النائي.

INTRODUCTION

A principal goal of soil moisture remote sensing research is the evaluation and development of remote sensing technology for measuring and monitoring soil moisture. A secondary goal is to improve existing water management procedures through the use of this technology. Methods used to measure soil moisture content can be divided into two broad classes. The first which relies on direct contact with the soil, includes the gravimetric, resistance, neutron probe and suction methods, among others. The remote sensing methods can be subdivided according to the region of the electromagnetic spectrum used for sensing the surface (Ulaby, 1974).

1- Visible remote sensing techniques.

2- Thermal Infrared techniques.

3- Microwave remote sensing techniques.

The dielectric constant of soil is found to be strongly dependent on moisture content (Pancholi and Khameshra, 1994; Srivastava and Mishra, 2004; Gadani and Vyas; 2008). The dielectric constant of soil is a measure of the response of the soil to an electromagnetic wave. This response is composed of two parts (real and imaginary), which determine the wave velocity and energy loss, respectively. In a non–homogeneous medium, such as soil, the bulk dielectric constant is a combination of the individual dielectric constants of its components (i.e. Air, water, dry soil, etc…), but is not a weighted average. The large contrast between the dielectric constant of air ($\varepsilon a \approx 1$), dry soil ($\varepsilon s \approx$ 2- 4) (Uluby *et al.*, 1986) and water ($\varepsilon_w \approx$ 80) in microwave region, results in a range of the bulk dielectric constant from 2 to 40 for a soil–water interface. Calla, (2000) has predicted that the microwave emission depends upon the dielectric constant of the soil. Further, (Sucher and Fox; 1963); (Vyas and Gadam, 2001) have measured the dielectric constant of dry and wet soil in frequency range (2GHz) to (20GHz). Yadav and Gandhi, (1992) suggested a simple microwave technique to measure the dielectric property of solids and their powder. The present study has undertaken to have a comprehensive idea of dielectric properties of sand soils of the Markib seashore, Libya.

In this paper, the experimentally determined values of the real and imaginary parts of the complex dielectric constant have been shown for sand samples with varied moisture content, and found that the dielectric constant of these soil samples increases slowly with increasing moisture content up to transition moisture, after which it increases rapidly with the increase in moisture content in the soil. From the measured value of dielectric constant, the emissivity and brightness temperature of soil at a given frequency can be calculated. The emissivity is an important parameter for microwave remote sensing, which provides information about soils. Thus the knowledge of variation of dielectric constant with moisture content of a soil is useful for the interpretation of data obtained for microwave remote sensing application, e.g. agriculture, hydrology and meteorology.

Interpretation and analysis of microwave measurements require model calculations of the brightness temperature for a range of moisture and temperature profiles. Several radiative transfer models have been developed for such calculations (Njoku and Kong,1977; Wilheit,1978). These models require detailed solutions of Maxwell's equations for electromagnetic waves propagating through stratified layers of the dielectric media. Accuracy of the calculations depends on the knowledge of the dielectric properties of the soil medium. The radiative transfer model developed by (Wilheit,1978) is particularly suited for calculating the brightness temperature of the dry and wet soil.

THEORETICAL CONSIDERATION

I-Relation between complex permittivity and propagation constant:

The propagation of electromagnetic wave through a medium depends upon the electrical conductivity, complex dielectric constant **(ε^*)**, magnetic permeability **(μ)**, and the frequency **(f)** through the propagation constant **(γ)**. The relative complex dielectric constant **(ε_r)** of the medium is defined by using the basic principles of Maxwell's equations (Stratton, 1944; Ramo *et al.*, 1965).

$$\varepsilon_r = \varepsilon^* / \varepsilon_o = \varepsilon_1 - j\varepsilon_2 \quad \text{.......1}$$

Where **ε_1** is the real part of the complex dielectric constant, **ε_2** is the imaginary part of the complex dielectric constant and **ε_o** is the free space permittivity. The real and imaginary parts of the dielectric constant are expressed (Ramo *et al.*, 1965) as**:**

$$\varepsilon_1 = (\beta^2 - \alpha^2) / w^2 \mu\, \varepsilon_o \quad \text{.......2}$$

$$\varepsilon_2 = 2\, \alpha\, \beta / w^2 \mu\, \varepsilon_o \quad \text{.......3}$$

Where **α** is the attenuation constant, **β** is the phase constant and **w** is the angular frequency of the wave. At microwave frequencies for non-magnetic materials (Sucher and Fox, 1963) such that **$\mu = \mu_0$ (**is the permeability of the free space), equations (2 and 3) are written as:

$$\varepsilon_1 = (\beta^2 - \alpha^2) / \beta_0^2 \quad \text{.......4}$$

$$\varepsilon_2 = 2\, \alpha\, \beta / \beta_0^2 \quad \text{.......5}$$

Where **β_0** is the phase constant of free space and is given as $\boldsymbol{\beta_0 = w \sqrt{\mu_0\, \varepsilon_0}}$ Thus the relative complex dielectric constant is expressed directly in terms of attenuation and phase constants of the material.

II –Computation of emissivity and brightness temperature

The microwave radiometer calculates brightness temperature **T_B** which is in general, a function of the physical temperature distribution in the subsurface and the dielectric properties of the medium(Lytle, 1974; Rosenkranz, 2003). The brightness temperature is simply expressed (Wilheit, 1978) as**:**

$$T_B = R\, T_{ground} + (1 - E_m)\, T_{sky} \quad \text{.......6}$$

Where $\mathbf{T_{ground}}$ = temperature of the ground (earth) in degree Kelvin, $\mathbf{T_{sky}}$ = temperature of the sky, and $\mathbf{E_m}$ = the effective emissivity which is related to the reflectivity **R** (Ramo *et al.*, 1965).

Emissivity depends on the dielectric constant and to a lesser degree on surface roughness. Although most natural earth surfaces are not electromagnetically smooth at microwave frequencies, however, the dependence of emissivity on surface roughness has been omitted in the present calculation. For a smooth surface, the emissivity in both polarization(p) is expressed as**:**

$$Em_p = 1-[R_p] \quad \ldots\ldots 7$$

In radiometry, it is seldom necessary to go beyond this Rayleigh- Jeans law. The maximum power that any material can radiate is that of a blackbody i.e. $\mathbf{0 < E_m < 1}$.

For a smooth surface, the reflection from a specular surface boundary is governed by Snell's law and is given by Hidy (1972); Yadav and Gandhi (1992).

$$R_{(H,V)} = [r_{(H,V)}]^2 \quad \ldots\ldots 8$$

$$R_H = [\{\mathrm{Cos}\theta - (\varepsilon_r - \sin^2\theta)^{0.5}\} / \{\mathrm{Cos}\theta - (\varepsilon_r - \sin^2\theta)^{0.5}\}]^2 \quad \ldots\ldots 9$$

$$R_V = [\{\varepsilon_r \cos\theta - (\varepsilon_r - \sin^2\theta)^{0.5}\} / \{\varepsilon_r \cos\theta - (\varepsilon_r - \sin^2\theta)^{0.5}\}]^2 \quad \ldots\ldots 10$$

Where R is the reflectivity in both horizontal and vertical polarization, r_H, r_V are power reflection coefficients in both (H,V) polarizations. $\boldsymbol{\varepsilon_r}$ is the relative complex dielectric constant $(\boldsymbol{\varepsilon_r = \varepsilon_1 - j\varepsilon_2})$ and $\boldsymbol{\theta}$ is the incidence angle relative to nadir**.**

EMPIRICAL MODEL OF DIELECTRIC CONSTANTSPACE FOR WET SOILS

An empirical model for the complex dielectric constant of soils as a function of moisture content was developed by Wang and Schmugge (1980), who expressed dielectric constant of a soil-water mixture in terms of dielectric constants of the constituents. Wang and Schmugge applied the regression analysis related to the values of transition moisture wt (cm^3/cm^3) and with wilting point wp (cm^3/cm^3) of the soils by the relation (Wang and Schmugge, 1980):

$$Wt=0.49*wp+0.165$$
$$\text{Parameter } \acute{\Omega}= 0.481- 0.57*wp$$

Where both Wt and $\acute{\Omega}$ have the dimensions of wp, which is a volume ratio (cm^3/cm^3). The wilting point defined as the soil moisture at which the release of water to a plant is too small to counter balance the transpiration losses. The wp can be calculated from the texture of the soils using the following relation (Wang and Schmugge, 1980):

$$Wp=0.06774-0.00064*sand\%+0.00478*clay\%$$

Sand and clay are the amounts (in percent) of sand and clay in the soil. The porosity P of soil can be calculated using the relations (Srivastava and Mishra, 2004; Gadani, and Vyas, 2008):

$$P= (G*\rho_w-\rho_s)/G*\rho_w$$

Where **G** is 2.65, and $\boldsymbol{\rho_w}$ is density of water and $\boldsymbol{\rho_s}$ is density of sample. The values of soil texture **wp, wt, δ,** porosity, and density of soil sample used in this study are shown in (table 1).

Table 1: Physical properties of the soil used for dielectric measurements.

Soil texture%			wilting point (cm^3/cm^3)	Transition moisture (cm^3/cm^3)	Skin depth (cm)	Density (gm/cm^3)	Porosity
Sand	Silt	Clay					
94	5.4	0.6	0.0095	0.1697	0.4759	1.70	0.3585
93	6.0	1.0	0.0120	0.1708	0.4741	1.72	0.3509
91	7.2	2.8	0.0229	0.1762	0.468	1.75	0.3396
86	11.8	2.2	0.0232	0.1764	0.4678	1.65	0.3774
96	3.2	0.8	0.0077	0.1688	0.4766	1.75	0.3396

SAMPLES PREPARATION AND EXPERIMENTAL RESULTS

The soil samples were collected from many places near Markib seashore of Mediterranean Sea, Libya in April 2002. Dry sand soil samples were prepared before carrying out the experimental observations. Samples were first evenly crushed into fine grains and then the sieved sample was heated to 110° C for half an hour. This dried out the sample completely and the sample was ready for the experiment. Wet soils were prepared and water-content on a weight basis was determined. The gravimetric soil moisture content (Wc%) was calculated using wet (W1) and dry (W2) soil masses following the relation: (Calla, 2000).

$$W_C\ \% = \frac{W1-W2}{W2} \times 100$$

Intensive experiments were carried out to measure the complex dielectric constant (**ε_1- jε_2**) of the soil using waveguide technique in the microwave frequencies with varying moisture content. The technique used in the measurement is shown in (Fig.1 A and B), the measurement procedure used was described in detail by (Sucher and Fox, 1963; Lytle, 1974; Ulaby, 1974 and; Singh and Singh, 1981). The statistical results of these measurements were shown in (Fig. 2). It was found that the dielectric constant (real and imaginary parts) of these soils increases only slowly with moisture content initially, and after reaching a transition point, it increases rapidly with increasing moisture content in the microwave frequency range.

The results were compared with those of Yadav and Gandhi (1992) and Njoku and Kong (1977). A qualitative difference between the present calculation and that of Chaudhari and Shinde (2008), Njoku and Kong (1977) was that the rate of increase in real part of the complex dielectric constant was more in case of 15% to 30% moisture content, whereas in case of Njoku and Kong (1977), the rate of increase was seen to be uniform. Such a difference between the results could be interpreted in terms of different types of soil used in the experiment. Yadav and Gandhi (1992), reported that when water was held in a soil in direct contact with the surface of the soil particles (absorbed), it was characterized to be very different from free water. In particular, the water within few molecules of clay particles might have dielectric constant as small as one–tenth of free water, probably due to the rest

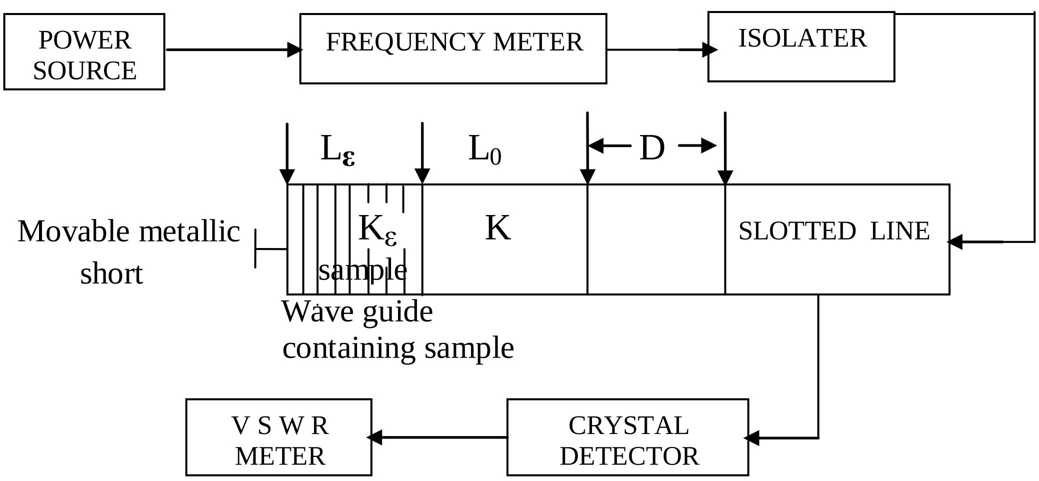


Fig. 1-A : Two Point Method of Measuring Dielectric Constant at λ= 2.8cm.

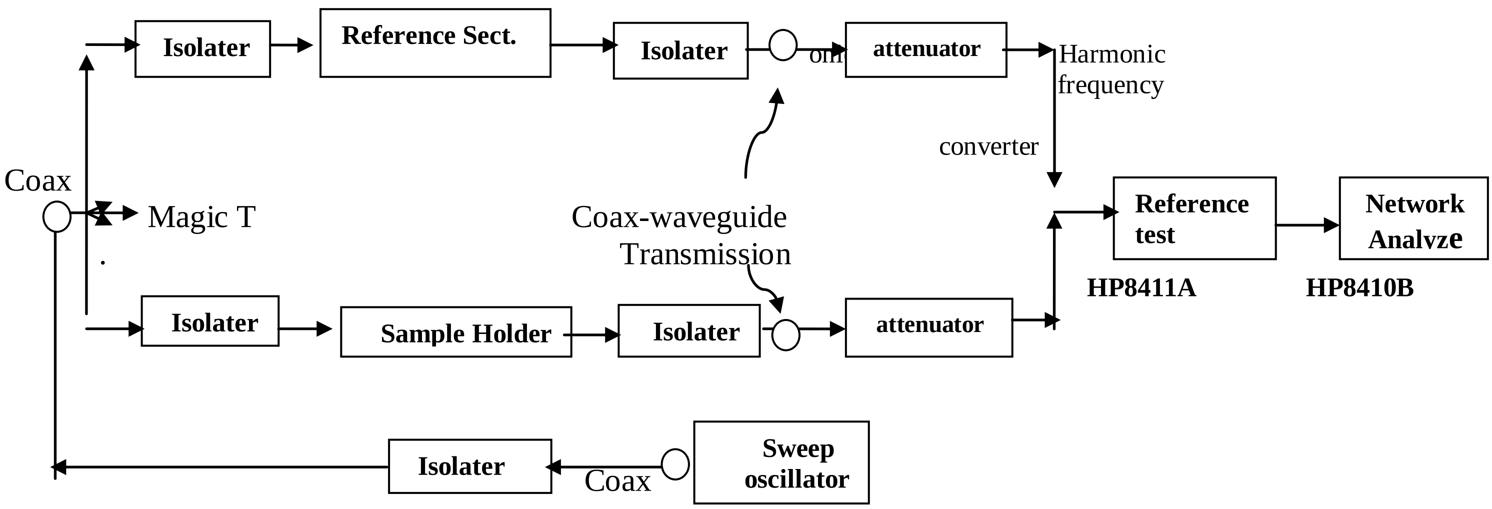


Fig. 1-B: Block Diagram of the Dielectric Measurement System at λ= 21cm.

RESULTS AND DISCUSSION

The measured values of the dielectric constant $(\varepsilon_1)_{Real}$ and $(\varepsilon_2)_{Imaginary}$ at microwave frequency for sandy soil samples are plotted against various values of moisture content. The results of these measurements are shown in (Fig. 2) and in (table 2). It is found that the dielectric constant (real and imaginary parts) of these soils increases slowly with moisture content initially, and after reaching a transition point, it increases rapidly. This observation is qualitatively in good agreement with the results of (Vyas, 1982; and Wang and Schmugge, 1980). At moisture contents below the transition point due to the presence of only few free water molecules, the mixture dielectric permittivities increase only slowly, whereas at moisture contents above the transition point, the number of free water molecules increases rapidly and hence a steep rise in permittivity is observed.

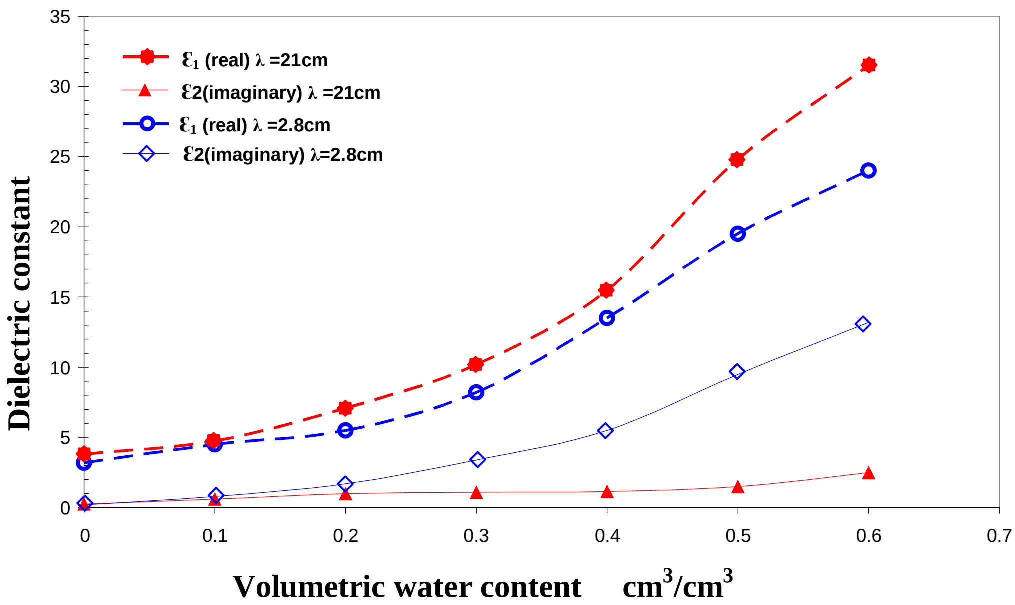


Fig. 2: Mmeasured Values of ε_1 and ε_2 Versus Moisture Content for Sandy Soils Samples at (λ =21cm and λ=2.8cm).

Table 2: The Measured Values of $\varepsilon_1$and ε_2 with Moisture Content of Sandy Soils at (λ =21cm and λ=2.8cm).

	Dielectric constant of soil λ =21cm		**Dielectric constant of soil λ=2.8cm**	
Moisture	(ε_1) Real	(ε_2) Imaginary	(ε_1) Real	(ε_2) Imaginary
0	3.8	0.25	3.2	0.2
0.1	4.75	0.6	4.5	0.8
0.2	7.1	1.0	5.5	1.7
0.3	10.2	1.1	8.2	3.4
0.4	15.5	1.15	13.5	5.5
0.5	24.8	1.5	19.5	9.5
0.6	31.5	2.5	24	13.2

Using these laboratory data, the reflectivity and emissivity of the surface medium have been computed at nadir and at varying look angles using the relations (7-10). The variation of the reflectivity and emissivity is shown in figures (3,4) respectively, tables (3, 4). The results show that the presence of moisture in soil causes a marked change in reflectivity and emissivity. The reflectivity is found to vary from 0.22 to 0.63, whereas emissivity changes in opposite direction and varies from 0.9 to 0.51 from dry surface to 30 percent moisture. The change in reflectivity and emissivity for a soil has been observed by trucks mounted radiometers in field experiment (Ulaby, 1974).

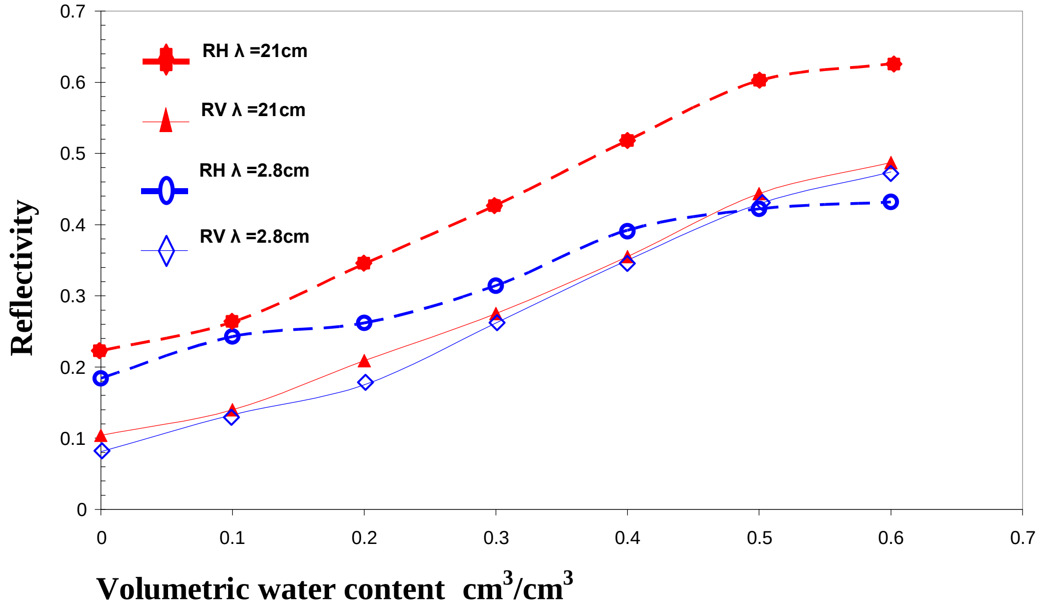


Fig. 3: Variation of Reflectivity with Moisture Content for Sandy Soils at (λ =21cm and λ=2.8cm).

Table 3: The Calculated Data of Reflectivity as a Function of the Moisture Content.

	λ =21cm		λ =2.8cm	
Moisture	R_H	R_V	R_H	R_V
0	0.223	0.104	0.184	0.081
0.1	0.263	0.140	0.243	0.133
0.2	0.345	0.209	0.262	0.175
0.3	0.427	0.275	0.314	0.262
0.4	0.518	0.355	0.392	0.350
0.5	0.602	0.4435	0.420	0.428
0.6	0.626	0.487	0.432	0.474

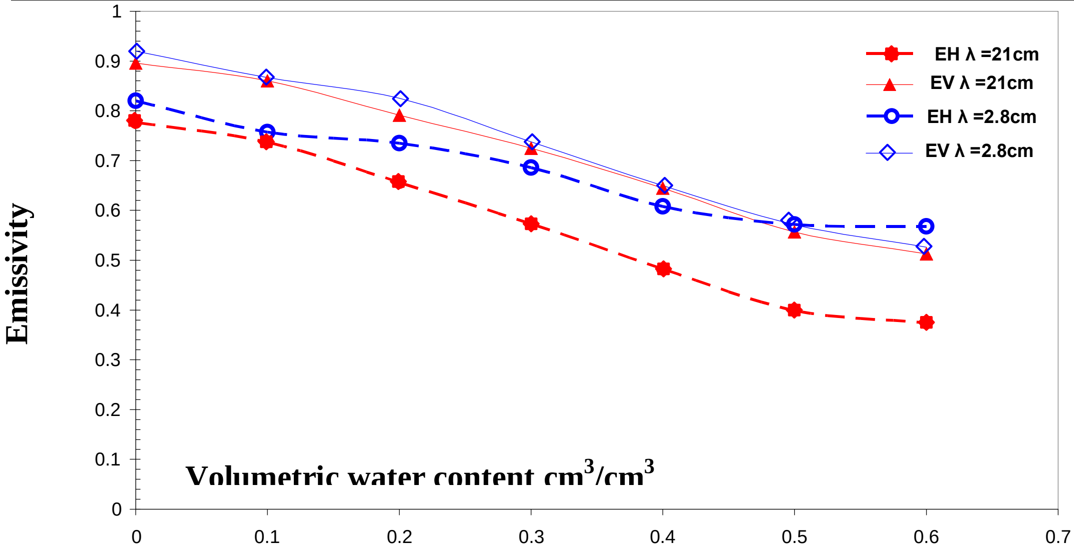


Fig. 4: Variation of Emissivity with Moisture Content for Sandy soils at (λ =21cm and λ=2.8cm).

Table 4: The Calculated Data of Emissivity as a Function of the Moisture Content.

	λ =21cm		λ =2.8cm	
Moisture	E_{mH}	E_{mV}	E_{mH}	E_{mV}
0	0.777	0.896	0.82	0.92
0.1	0.737	0.860	0.757	0.867
0.2	0.656	0.791	0.735	f0.825
0.3	0.573	0.725	0.686	0.738
0.4	0.482	0.645	0.608	0.650
0.5	0.399	0.557	0.572	0.571
0.6	0.374	0.513	0.568	0.526

As the moisture content of soil increases, the reflectivity increases, whereas the emissivity decreases and the brightness temperature also decreases, the data are explained in (Fig. 5) and shown in (table 5). The results in (Fig. 3 , 4 and 5) also show a small variability due to frequency for the cases considered at any moisture content.

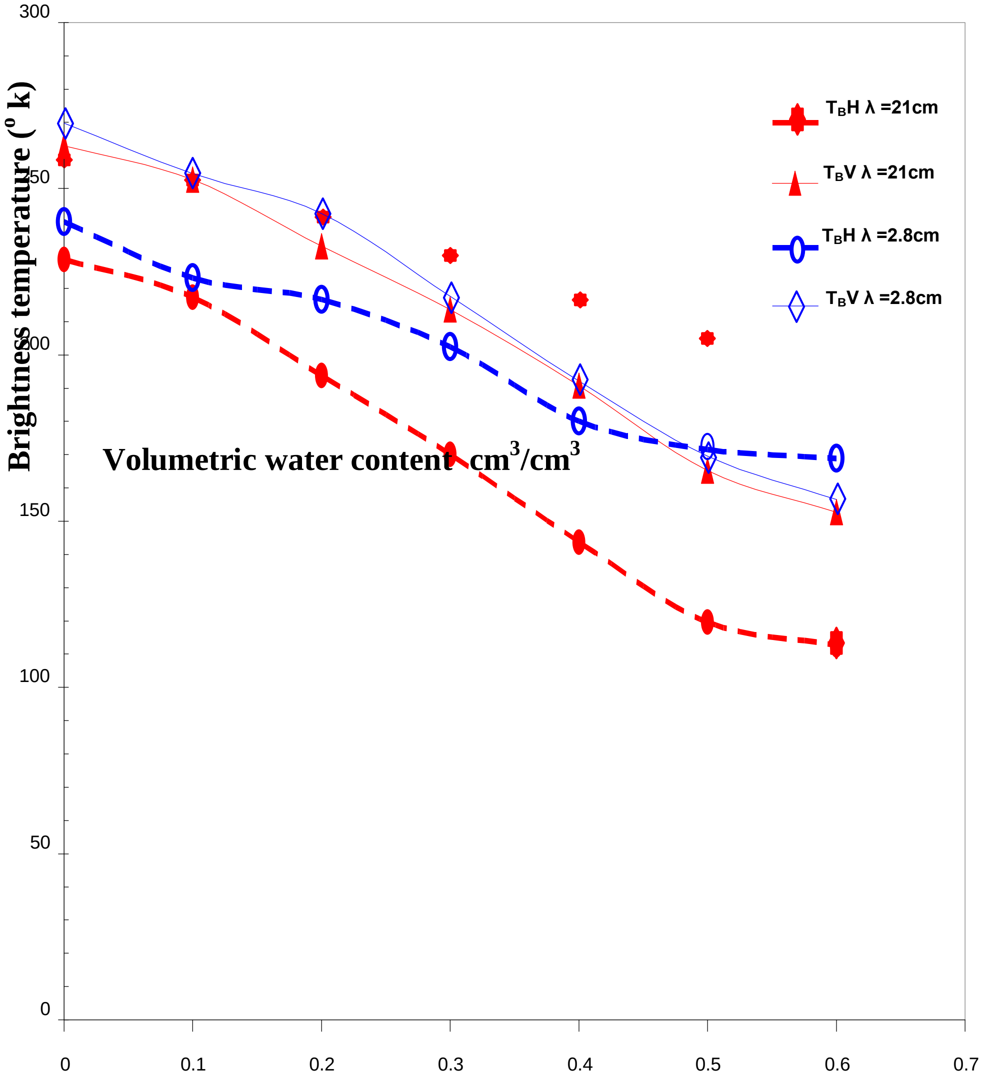


Fig. 5: Variation of Brightness Temperature with Moisture Content for Sandy Soils at (λ =21cm and λ=2.8cm).

Table 5: The Calculated Data of Brightness Temperature as a Function of the Moisture Content.

	λ =21cm		λ =2.8cm	
Moisture	T_{BH}	T_{BV}	T_{BH}	T_{BV}
0	228.67	262.99	240.1	269.8
0.1	217.349	252.724	223.139	254.580
0.2	193.745	232.730	216.61	242.62
0.3	170.039	213.685	202.491	217.582

0.4	143.723	190.838	180.073	192.089
0.5	119.543	165.278	171.556	169.572
0.6	112.811	152.621	168.87	156.56

It has also been found from (Fig. 6),(A, B) and (table 6), (A, B) that the emissivity decreases at larger angles of incidence for horizontal polarization, whereas it increases for vertically polarized case with increasing incidence angle to a maximum occurring at the Brewster angle. It has also been observed that the incident angle, at which the Brewster angle occurs, shifts toward grazing for higher moisture content.

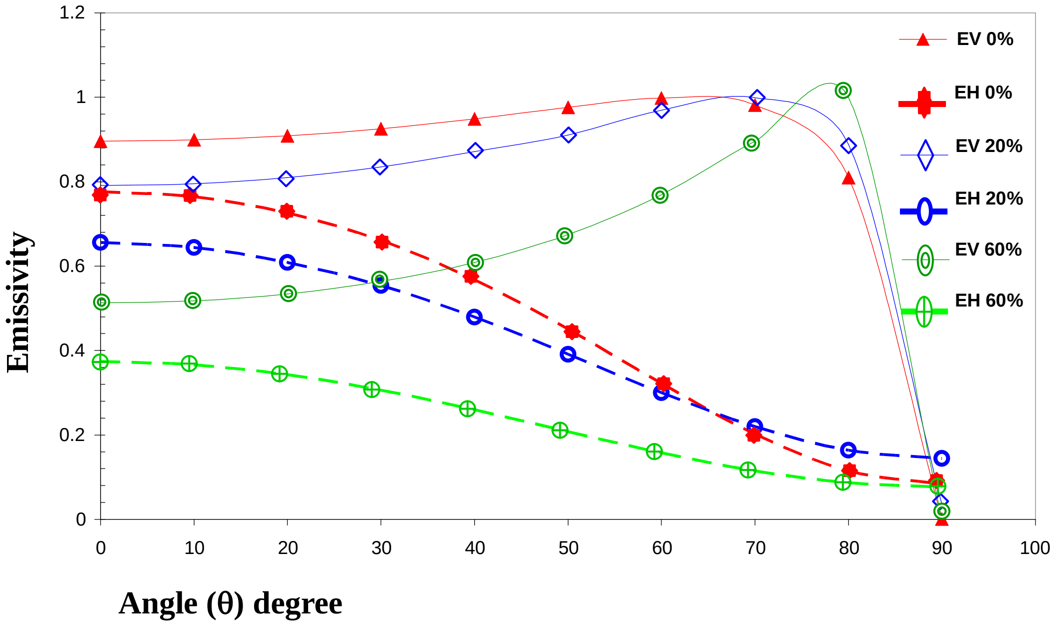
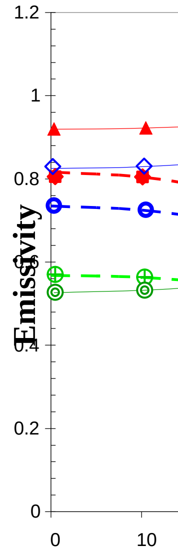


Fig. 6 A: Model of Calculated Emissivity as a Function of the Angle at a λ =21cm, the Ascending Curve is for Vertical and the Descending Curve is for Horizontal Polarizations.

Table 6 A: The Calculated Data from Model for Emissivity at Moisture (0,20%,60%) as a function of angle at λ =21cm.

	moisture=0%		**moisture=20%**		**moisture=60%.**	
Angle	E_{mH}	E_{mV}	E_{mH}	E_{mV}	E_{mH}	E_{mV}
0	0.7766	0.8958	0.656	0.7909	0.374	0.513
10	0.7643	0.8991	0.644	0.7954	0.366	0.518
20	0.7263	0.9090	0.609	0.8100	0.343	0.534
30	0.661	0.9256	0.554	0.8350	0.306	0.564

40	0.5675	0.9488	0.4791	0.8711	0.260	0.609
50	0.4505	0.9762	0.3910	0.9110	0.208	0.675
60	0.3217	0.9980	0.300	0.9696	0.158	0.769
70	0.2016	0.9815	0.2196	0.9989	0.115	0.896
80	0.1150	0.8095	0.1640	0.8878	0.0869	0.999
90	0.0833	0.00042	0.1441	0.00053 6	0.0769	0.00106



Angle (θ) degree

Fig. 6 B: Model of Calculated Emissivity as a Function of the Angle at λ =2.8cm, the Ascending Curve is for Vertical and the Descending curve is for horizontal polarizations.

Table 6 B: The Calculated Data from Model for Emissivity at Moisture (0,20%,60%) as a Function of Angle at λ =2.8cm.

	moisture=0%		**moisture=20%**		**moisture=60%.**	
Angle	**E_{mH}**	**E_{mV}**	**E_{mH}**	**E_{mV}**	**E_{mH}**	**E_{mV}**
0	0.8162	0.9195	0.735	0.825	0.568	0.526
10	0.8042	0.9222	0.725	0.829	0.563	0.532
20	0.7672	0.931	0.695	0.843	0.546	0.548
30	0.7021	0.945	0.646	0.866	0.521	0.578
40	0.6071	0.964	0.58	0.898	0.488	0.623
50	0.485	0.985	0.501	0.939	0.452	0.689
60	0.3474	0.9998	0.419	0.981	0.417	0.781
70	0.21627	0.9732	0.347	0.991	0.387	0.901
80	0.12022	0.7906	0.296	0.856	0.368	0.984
90	0.08474	0.0004	0.278	0.00048	0. 361	0.00096

For uniform moisture content and temperature distribution, the brightness temperature of the surface has been computed in both polarizations using the relation in equation (6) as in (Table 7 A, B). (Fig. 7 A, B) show the brightness of the medium, and is found to vary from 262°K from dry soil down to 152°K for wet soil. It has also been observed that brightness is independent of frequency. (Fig.7A, B) illustrates the use of microwave radiometers to locate the moisture.

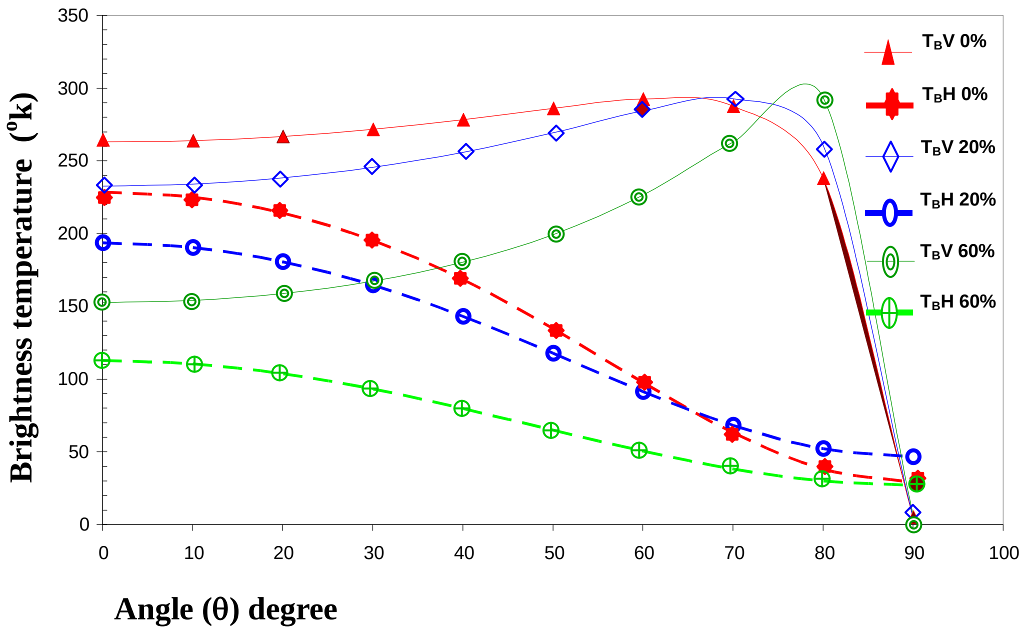


Fig. 7 A: Emission Model Predictions of Brightness Temperature for Sandy soil as a Function of the Angle at λ =21cm, the Ascending Curve is for Vertical and the Descending Curve is for Horizontal Polarizations.

Table 7 A: The Calculated Data from Model for Brightness Temperature at Moisture (0,20%,60%) as a Function of Angle at λ =21cm.

	moisture=0%.		moisture=20%.		moisture=60%.	
Angle	T_{BH}	T_{BV}	T_{BH}	T_{BV}	T_{BH}	T_{BV}
0	228.67	262.99	193.7448	232.73	112.811	152.621
10	225.11	263.93	190.469	234.10	110.505	154.154
20	214.17	266.78	180.674	238.296	103.769	158.901
30	195.32	271.58	164.584	245.495	93.180	167.343
40	168.43	278.27	142.983	255.91	79.737	180.375
50	134.73	286.13	117.617	269.389	64.877	199.448
60	97.66	292.44	91.414	284.252	50.382	226.599
70	63.06	287.67	68.262	292.70	38.181	263.021
80	38.13	238.13	52.240	260.7	30.028	292.89
90	29.00	0.000512	26.5	0.0005154	27.161	0.0005304

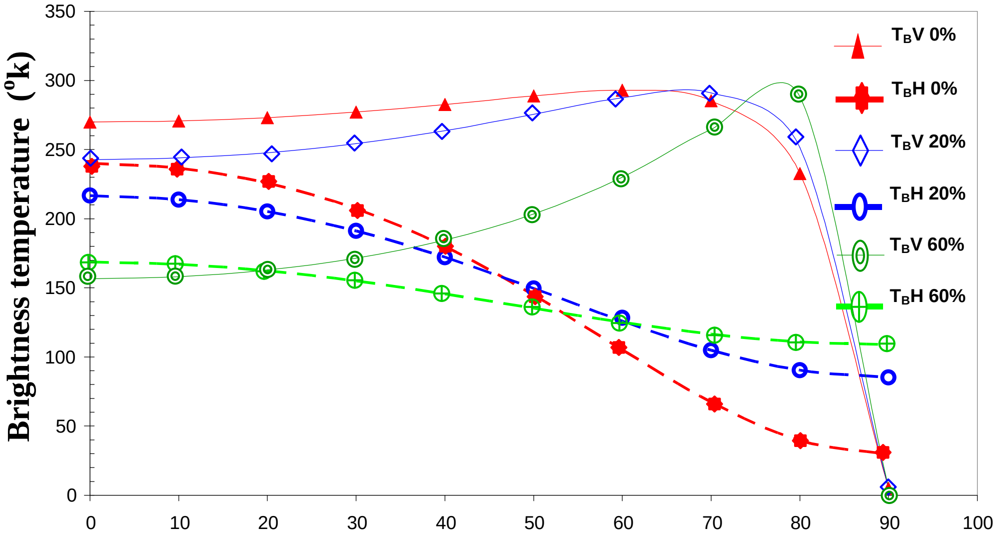


Fig.7 B: Emission Model Predictions of Brightness Temperature for Sandy Soil as a Function of the Angle at λ =2.8cm, the Ascending Curve is for Vertical and the Descending Curve is for Horizontal Polarizations.

Table 7 B: The Calculated Data from Model for Brightness Temperature at Moisture (0,20%,60%) as a Function of Angle at λ =2.8cm.

	moisture=0%		moisture=20%		moisture=60%.	
Angle	T_{BH}	T_{BV}	T_{BH}	T_{BV}	T_{BH}	T_{BV}
0	240.1	269.82	216.61	242.62	168.686	156.564
10	236.62	270.61	213.77	243.89	167.079	158.114
20	225.94	272.998	205.25	247.75	162.383	162.91
30	207.20	277.02	191.15	254.33	154.995	171.414
40	179.89	282.54	172.03	263.71	145.609	184.478
50	144.68	288.80	149.39	275.48	135.227	203.440
60	105.06	292.9303	125.82	287.43	125.098	230.035
70	67.28	285.2871	104.90	290.88	116.571	264.549
80	39.62	232.6835	90.37	251.48	110.873	288.263
90	29.41	0.005115	46.16	0.00514	64.869	0.005275

Microwave energy, which is radiated from the earth's surface, is polarized in both horizontal and vertical planes. The computed values of brightness temperatures of water-bearing soils are in both polarizations. The vertical polarized microwaves read out higher brightness temperature, and is maximum at the Brewster angle about70°-80° whereas the horizontally polarized microwaves show the lesser values for the same moisture content of decreasing trend. Therefore, the use of both polarizations are potentially useful to estimate the moisture content of soil. These parameters (emissivity and brightness temperature) have been widely used in developing inversion model, which is helpful for interpretation of remote sensing data obtained by air-borne satellite and ground-based satellite. The brightness temperature and emissivity of earth's surfaces are obtained by ground-based or satellite-base. Sensors are inverted to laboratory measured microwave parameters using suitable inversion algorithms for deriving soil moisture.

CONCLUSION

The conclusions obtained from this study are as follows:

1- Soil moisture is a very important geosciences parameter for both application and scientific research purposes. The soil moisture monitoring is certainly possible by passive microwave radiometry, but the questions of how much soil could be monitored, its moisture range and how the types of soil affect the accuracy of the monitor are not yet clear. Therefore, these problems along with some parameters which affect the microwave signature, require detailed study to develop an appropriate inversion model.

2- Additional experiments are also required to demonstrate the feasibility of obtaining the required temperature measurements from aircrafts as possibly satellite-based remote sensors and to more precisely the depth to which water contents may be inferred from surface temperature measurements.

Nomenclature:

(ε_1) Real = Dielectric constant (real value).
(ε_2) Imaginary = Dielectric constant (image value).
P = Polarization.
H = Horizontal polarization.
V = Vertical polarization.
R = Reflectivity.
E_m = Emissivity.
T_B = Brightness temperature.
T_{ground} = Surface temperature (Physical temperature).
T_{sky} = Sky temperature.
L_ε = Length of sample in the waveguide.
L_0 = Length in the empty waveguide.
K = The propagation constant (in the empty waveguide).
K_ε = The propagation constant (with sample in the waveguide).
D = The position of the minimum in the slotted line, with respect to the reference plane(D=0).

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