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FIELD AND LABORATORY CALIBRATION OF WATER CONTENT AND DIELECTRIC PERMITTIVITY OF PONTIAN PEAT SOIL, SOUTHWEST MALAYSIA

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ABSTRACT

Water content is a significant component of a peat ecosystem and plays a key role in the control and temporal transformation of the system. There is however no standard empirical model for the prediction of peat water content from the dielectric constant, as is the case of mineral soils. In this work, we calibrated the measured dielectric constant with the water content of Pontian peat soil, southwestern Johor, Malaysia, with the aim of developing a model for the assessment of water content of the resources with radar instruments. Comparative analysis of the results obtained with some existing models shows that a third order polynomial equation gives the best fitting (R^2=0.947). The model equation was used to estimate the water content of the study area from ground penetrating radar (GPR) image acquired within the area. Analysis of the results with existing model equations show that both the nature and the fitting coefficients vary with location due to the variation in vegetation cover and therefore reaffirmed the need for site-specific calibration with respect to a given locality.

KEYWORDS: Peat soil, dielectric permittivity, water content, Ground Penetrating Radar.

INTRODUCTION

Hydrogeological properties of peat are of economic and environmental significance as they determine the conditions of important processes such as chemical infiltration, evaporation, subsurface pathways for mineral ions and movement of agrochemicals. Agriculture researchers perform assessment of soil and organic resources quality by monitoring the moisture level of the soil (Janier and Maidin, 2011). Accurate measurement of peat's water content is therefore a critical requirement for the management and sustainable development of the resources.

The application of radar signals in the measurement of soil water content within the vedose zone has been in practice for a long time. Various radar-based instruments for water content measurement were developed such as Hygrometric Measurement Network (HYMENET) (Ahmad *et al*, 2006); Time-Domain Reflectometry (TDR) (Maroufpoor *et al*, 2009); Capacitive sensor (Gardner *et al*, 1998), Ground Penetrating Radar (Kalogeropoulos *et al*, 2011) etc. Most of the techniques exploit the high dielectric constant of free water in a multi-phase soil system in estimating the quantity of water in the soil mixture. Dielectric permittivity is a complex frequency-dependent electrical property of materials which is a measure of the effect of applied electric field to the orientation of the molecules of the material medium. Ordinarily, soil is a multi-phase mixture of sand, water, air and other dissolved cations. In the vicinity of applied electromagnetic (EM) field, the dipole distribution of water molecules in soil effectively aligns within the applied field giving raise to higher magnitude of dielectric permittivity. Thus the presence of water in soil is a dominant factor in the effective dielectric permittivity value of the soil.

The application of electromagnetic techniques in soil water content assessment is mostly based on the empirical relationship between fractional water content and the measured dielectric permittivity. Various empirical relationships were developed mostly based on the laboratory measurements of these two parameters. The most remarkable relationship is the Topp equation, which relates the water content θ and its apparent (measured) dielectric permittivity ε_r (Topp *et al*, 1980). For soil of various textures, this is given as

$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}\varepsilon_r - 5.5 \times 10^{-4}\epsilon_r^2 + 4.3 \times 10^{-6}\epsilon_r^3 \quad \ldots\ldots(1)$$

The dielectric permittivity is determined from the measure of the radar propagation velocity *v* according to the relation (Brosten *et al*, 2009):

$$\varepsilon_r = \left(\frac{c}{v}\right)^2 \quad \ldots\ldots(2)$$

where *c* is the velocity of EM waves in free space. Topp's equation is generally applicable to various types of mineral soils as it was used to estimate volumetric water content from zero to saturation.

The limitation of Topp equation is that organic, peat and clay soils tend to deviate from it. This fact was described by Pumpanem and Ilvesniems (2005) who state that the relationship between the dielectric constant and water content in organic soil is very different from that in mineral soil due to the differences in bulk density and surface area. Deviation of peat soil from Topp's equation is attributed to some factors uniquely affecting the relationship between water content and dielectric permittivity of clay. These include among others: significantly high imaginary part of the relative permittivity of the soil and high content of bound water with lower relative permittivity than free water (Cosenza and Tabbagh, 2004).

Various empirical equations were developed relating dielectric constant and water content of peat soils. In assessing the relative performance of three different model equations for peat soil water content estimation, Pumpanem and Ilvesniems (2005) observed that although the logarithmic model was found to have the best fit, the fitting parameters vary with site-specific characteristics due to variation in the type of vegetation cover.

In a similar analysis, the shapes of the plots of ten different dielectric permittivity: water content calibration curves for organic soil conducted by Oleszczuk *et al,* (2004) showed a variation in water content for a given dielectric value in all the curves. They attributed the variation to the change in bulk density of peat for a given amount of water content. The bulk density of peat depends on the structure and degree of decomposition of the deposit (Huat *et al,* 2011). This fact was earlier highlighted by Wust *et al,* (2003) who state that the bulk density of organic soil increases with an increase in the level of decomposition of the deposit. The decompositional level of peat deposit on the other hand depends on the type and parts of the plant species that accumulate to form the deposit (Xuehui and Jinming, 2009). Various types and part of plant species decompose at different rates depending on their fiber content. Thus peat‘s structure and properties are greatly dependent on the type of plant forming community. There is therefore a need for site-specific calibration of dielectric constant and water content for different locations.

The objective of this work is to develop a model for the inversion of apparent (measured) dielectric permittivity of Pontian peat soil obtained from GPR radar into water content uniquely relative to the area. This is against the background of the relevance of tropical peat bog to socioeconomic and environmental development of the region and the complex variation in petrophysical properties of the bog with climatic conditions. The work involves laboratory experiments and mathematical modeling of parametric equations developed for other peat deposits from previous works. Laboratory experiments were conducted to determine the dielectric permittivity and water contents of pairs of peat subsamples from various depth positions. Regression analysis was used to obtain the mathematical relationship between the two sets of data with optimal coefficient of determination. The most optimal model equation was used to estimate subsurface distribution of water content of the deposit from radar images acquired close to the sampling site.

METHOD AND MATERIALS

The study area is Pontian peatland, in the southwest coastal region of Peninsula Malaysia (Fig. 1). Peat samples were collected at a junction of Jalan Parit Haji Adnan, Kampuung Seri Menanti, (long.103^{o}27'49.94"E, lat. 1^{o}35'15.16"N) close to Pekan Nenas, Pontian district, Johor Malaysia. The area is a portion of the coastal plain of southwestern Johor described by ASANUS (1991) as largely underlain with marine clay, silt and the paludal peat deposit of Holocene age.

Undisturbed peat samples were collected at a depth interval of 0.5m from the surface to a maximum depth of 2.5m using a 30cm diameter cylindrical sampler. The samples were carefully sealed and packed in an appropriate container that minimizes the effect of vibration during transportation. Two experiments were conducted to determine the dielectric permittivity and the water content of the soil sub sampled at each sampled depth.

Determination of the Dielectric Constant of Peat Samples

The principle of capacitive circuit was used to determine the dielectric constant of the peat sample. Based on the principle, the relative dielectric permittivity ε_r of a material is given as the ratio of the capacitance of a capacitor C_s with the material as dielectric to the capacitance of the same capacitor with air (or free space) as dielectric material (Young, 2012). That is;

$$\varepsilon_r = \frac{C_s}{C_0} \qquad (3)$$

A simple capacitive circuit was designed to measure the capacitance of parallel plates capacitor of known geometric dimension designed to contain the soil sample as dielectric material (Fig. 2). The potential drop V_c across the plates is given by;

$$V_c = IX_c \qquad (4)$$

where X_c is the capacitive reactance of the capacitor given by;

$$X_c = \frac{1}{2\pi f C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

and f is the signal frequency. Thus the capacitance of the capacitor with air as dielectric C_0 can be obtained from the slope S_0 of the I-V plot as;

$$C_0 = \frac{1}{2\pi f S_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

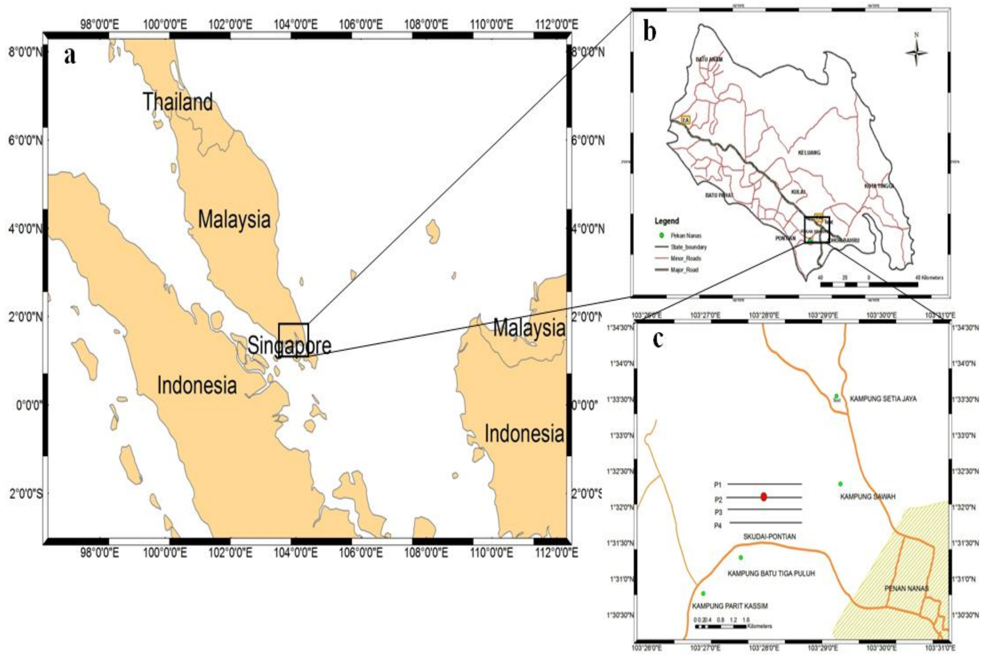

Figure1: Map of the study area; (a): Global map of the region, (b): location of the study area, (c) scanned profiles and core sampling site (red dot).

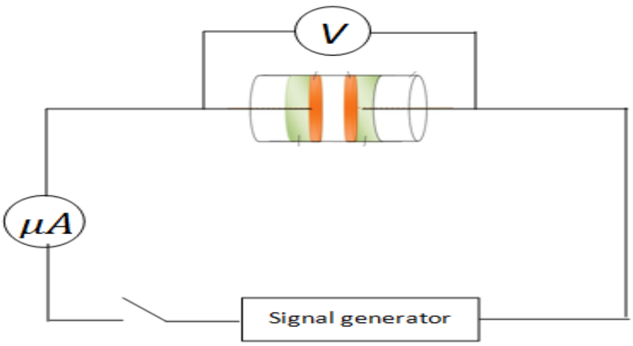

Figure 2: Capacitive circuit for dielectric constant measurement

The capacitance of a parallel plate capacitor in term of its geometry is given by Young (2012) as;

$$C_0 = \frac{\varepsilon_0 A}{d} \qquad (7)$$

where A is the area of the plates and d is the separation between them. The dielectric permittivity of air ε_0 can therefore be obtained from the slope of the plot of C_0 against $1/d$. In practice, the connecting cables and the measuring instruments have significant self capacitances that affect the resultant capacitance. Thus the capacitance can practically be expressed as;

$$C_0 = C_{er} + \frac{\varepsilon_0 A}{d} \qquad (8)$$

where C_{er} is the error due to the effect of the capacitance of the connecting cables and measuring instruments. This error appears as the intercept in C_o axis in the C_0-$1/d$ plot and can therefore be removed by subtracting it from the measured C_o as follows;

$$C_0 - C_{er} = \frac{\varepsilon_0 A}{d} \qquad (9)$$

The relative dielectric permittivity is therefore given as;

$$\varepsilon_r = \frac{C_s - C_{er}}{C_0 - C_{er}} \qquad (10)$$

A high frequency variable signal generator was used as a source and a high sensitive digital a.c micro ammeter and voltmeter were used to record the currents I and the voltage V_c across the capacitor. The setup was first used to measure the dielectric permittivity of air using empty-space capacitor. After several trials, it was observed that an appreciable response was obtained at a signal frequency of 10MHz. This frequency was chosen for the experiment as the observed current is too low to be accurately recorded at higher frequency.

C_0 values were computed from the slope of the I-V_c plots based on equations (4) and (6) for various plate separations. The computed C_0 values were plotted against the inverse of their respective plate separations as shown in Fig. 3. The dielectric permittivity of air ε_0 as measured by the capacitor is $4.28893 \times 10^{-11} F/m$ while the error in capacitive measurement due to the effect of the capacitance of the circuit components and lead cables is $C_{er} = 8.0 \times 10^{-13} F$ (intercept of the plot on the vertical axis).

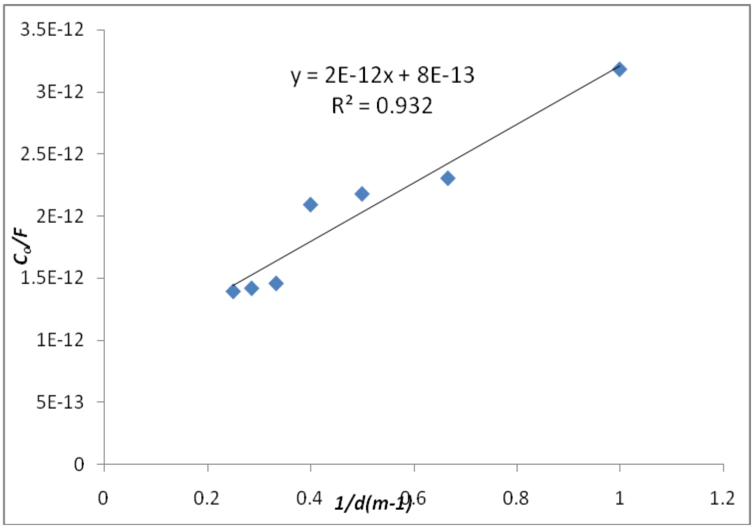

Figure 3: Plot of the capacitance of air-filled capacitor against plate separation.

Peat subsamples representing depths of 0-0.5m, 0.5-1.0m, 1.0-1.5m, 1.5-2.0m and 2.0-2.5m were gently placed into the cylinder of the parallel plate capacitor using a portable bench extruder with minimal disturbance. The *I-V* readings were recorded for a plate separation equal to the peat thickness. The capacitance with respect to each depth position C_i was computed using the slope of the respective *I-V* plot based on equations (4) and (6). The computed capacitances were used in equation (10) to compute the relative dielectric permittivity ε_r with respect to each depth sample.

Laboratory Determination of Water Content

Experimental determination of water content of the sampled peat soil was done based on the American Society for Testing and Materials (ASTM) standard for soil water content estimation published as ASTM D 2974-71 (ASTM D2974-07, 2007). According to this standard, the gravimetric water content θ_g of a peat soil is expressed as a percentage or fraction of oven dried mass of the sampled peat to the mass of as-received sample, given mathematically as;

$$\theta_g = \frac{M_s - M_d}{M_s} \qquad \text{.......................(11)}$$

where M_s is the mass of as–received sample specimen and M_d is the mass of the specimen after oven–dried to a constant mass.

A set of peat subsamples were prepared from each of the six depth positions. The masses of the labeled subsamples were recorded with a high precision balance. The specimens were then placed in the oven to completely dry to a constant mass at 105°C for 24 hours. The dried samples were sealed with aluminium foil and placed in a desiccator to cool for about an hour. The masses of the dried specimens M_d were then measured.

The computed gravimetric water contents were converted to volumetric water content using the bulk density of the soil. Bulk density of each subsample was determined experimentally as the ratio of the mass of the dried sample to the volume of as-received soil sample. The soil was collected from the subsamples for this purpose by inserting a shaft-edged cylinder of known volume. Each collected subsample was oven-dried and weighted after cooling in a desiccator. Based on the definition of gravimetric and volumetric water contents (ASTM D 2216-10, 2010), the two are related by the equation;

$$\theta_v = \theta_g \left(\frac{\rho_b}{\rho_w}\right) \quad \text{.......................(12)}$$

where ρ_b and ρ_w are the bulk density of the soil and the density of water respectively. Thus equation 12 was used to convert the gravimetric water content to volumetric water content based on the fact that water has a density of unity.

RESULTS AND DISCUSSION

The computed capacitances and the dielectric constants of the peat samples are shown in Table 1**.** Table 2 gives the computed water content for each of the sampled depth while Fig.4 shows the plots of the variations of the dielectric permittivity and water content with depth with respect to the sampled core.

Dielectric constant: water content calibration

The calibration of ε_r:θ with respect to the study area was accomplished using regression analysis. Mathematical modeling was performed with the aim of obtaining the optimal model equation for the relationship between the two variables. The four most common empirical equations put forward by previous authors for the prediction of soil water content from dielectric constants were used in the modeling. They are;

- Linear model (Persekian and Slater, 2011)

  $$\theta = a\varepsilon_0 + b$$

- Logarithmic model (Pumpunen and Ilivesniemi,, 2005)

  $$\theta = a\ln\varepsilon_r + b$$

- Second order polynomial model

  $$\theta = a\varepsilon_r^2 + b\varepsilon_r + c$$

- Third order polynomial modeling Topp *et al*, 1980)

  $$\theta = a\varepsilon_r^3 + b\varepsilon_r^2 + c\varepsilon_r + d$$

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Table 1: Computed dielectric permittivity of peat samples for different depth positions

d/m	C_0/F	C_i/F	$\varepsilon_r = \frac{C_i - C_{er}}{C_0 - C_{er}}$
0.0	3.18309E-12	3.769E-11	15.47887
0.5	3.18309E-12	9.296E-11	38.67419
1.0	3.18309E-12	9.335E-11	38.83434
1.5	3.18309E-12	5.773E-11	23.88807
2.0	3.18309E-12	1.072E-10	44.63731
2.5	3.18309E-12	1.053E-10	43.86345

Table 2: Water content computation

Depth/m	M_s/g	M_d/g	$\theta_g = \frac{M_s - M_d}{M_s}$	ρ_b (g/cm^3)	$\theta_v = \theta_g \left(\frac{\rho_b}{\rho_w}\right)$
0.0	45.118	14.592	0.676559	1.1340	0.7672
0.5	30.820	2.599	0.915672	0.8683	0.7951
1.0	27.219	2.749	0.899040	1.0427	0.9374
1.5	45.173	4.792	0.893919	1.0146	0.9070
2.0	45.833	3.594	0.921585	0.9319	0.8588
2.5	34.139	2.865	0.916078	1.0221	0.9363

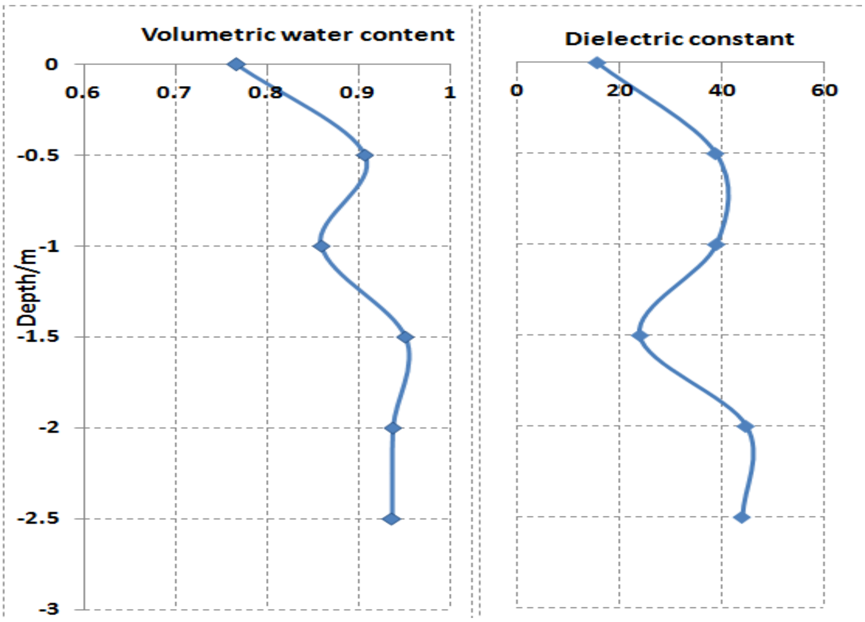


Figure 4: Variations of dielectric permittivity water content with depths at the sampled position.

Fig.5 shows the fitting curves obtained with respect to the four models. The fitting parameters for each of the models and their respective coefficient of determination R^2 are summarized in Table 3. It could be observed that with a fitting coefficient of 0.947, the third order polynomial equation gives the most accurate empirical relationship between the two parameters with respective to the study area. The equation can be written in term of the fitting parameters as;

$$\theta_v = 6.0 \times 10^{-5}\varepsilon_r{}^3 - 6.0 \times 10^{-3}\varepsilon_r{}^2 + 1.85 \times 10^{-1}\varepsilon_r - 8.9 \times 10^{-1} \quad (13)$$

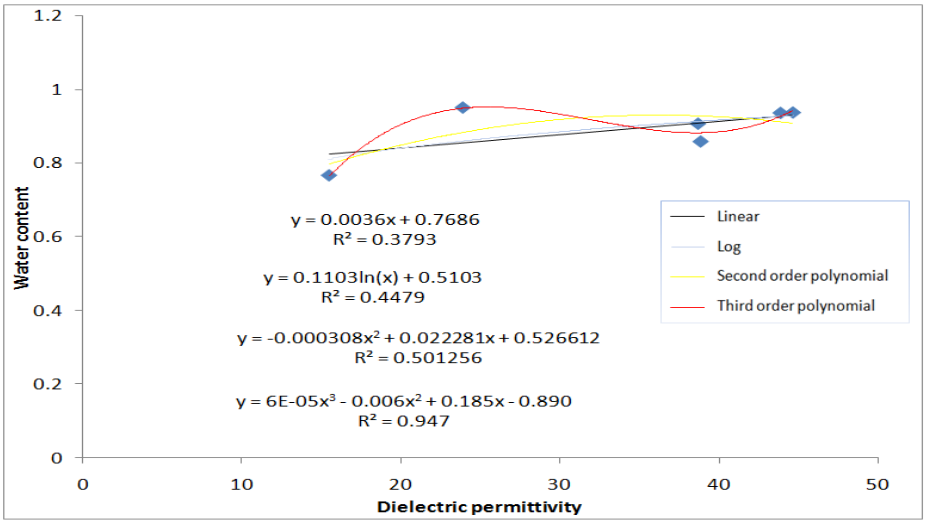


Figure 5: Fitting curves for the calibration of dielectric constant and water content with respect to linear, logarithmic, second order polynomial and third order polynomial models.

Table 3: Modeling results

Model equation	Fitting parameters				R^2
	a	***b***	***c***	***d***	
$\theta = a\varepsilon_0 + b$	0.0036	0.7686			0.3793
$\theta = aln\varepsilon_r + b$	0.1103	0.5103			0.4479
$\theta = a\varepsilon_r^2 + b\varepsilon_r + c$	-0.000308	0.022281	0.526612		0.5011
$\theta = a\varepsilon_r^3 + b\varepsilon_r^2 + c\varepsilon_r + d$	0.00006	-0.006	0.185	-0.890	0.9470

Water content estimation with ground penetrating radar

The derived empirical equation was used to estimate the subsurface water content of the peat deposit with ground penetrating radar. The study area was scanned with a 200MHz IDS GPR radar acquisition unit along four profiles of lengths 20m at equidistance separation of 4m. The acquired radar images were processed with Reflexw radar image processing software (Sandmeier, 2010). The following processing steps were applied using appropriate impulse response filters in order to enhance the signal-to-noise ratio and improve the image quality: subtract mean (dewow), static correction, manual gain and background removal.

Radar signal velocities were estimated using hyperbolic curve fitting. Reflection and diffraction hyperbolas associated with isolated and linear reflectors were mapped by repeating the scanning at three different strike angles close to a reference profile. The processed radargrams for the three strikes associated with each profile were compared in order to observe the variation of the eccentricity of the hyperbolic curves with strike direction. Curves whose eccentricity varies with strike direction are considered to be associated with linear features and hyperbola with the lowest eccentricity is considered to be as a result of strike perpendicular to the direction of the feature. These hyperbolas (with the lowest eccentricity) were used for the velocity estimation. Fig. 6 shows the window snapshots of the adopted hyperbolas along profile 1 transect.

The velocities obtained from the hyperbolic fittings were converted to dielectric constant using equation 2 where c = 0.3m/ns (radar velocity in air). The dielectric values obtained were used to compute the volumetric water content based on equation (13). Fig. 7 (a to d) are the plots of the spatial distribution of the water content of the peat deposit obtained across the scanned transect using the model equation. The statistical distributions of the water content across the four scanned profiles are given in the boxplot of Fig. 8.

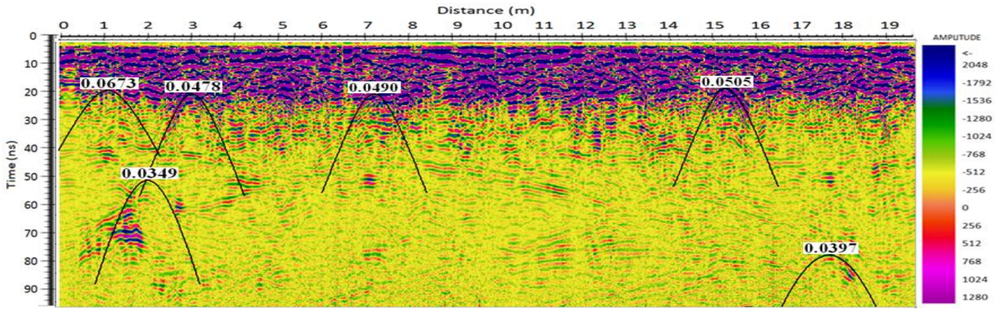
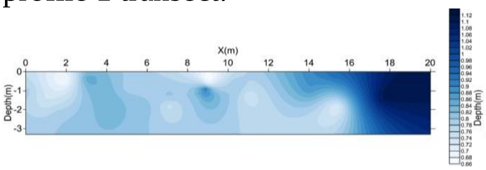
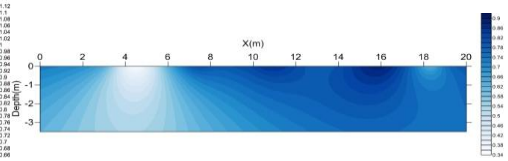


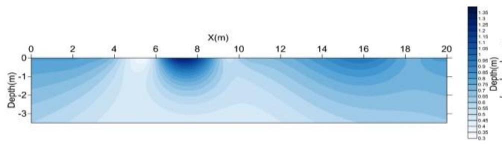
Figure 6: Velocity values obtained from hyperbolic velocity adaption along profile 1 transect.



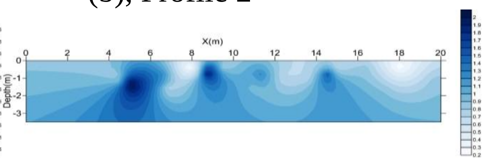
(a), Profile 1



(b), Profile 2



(c), Profile 3



(d), Profile 4

Figure 7: Cross sectional plot of the spatial distribution of water content obtained from the four scanned transects

DISCUSSIONS

A non linear third order polynomial model equation for computing the water content of peat soil from dielectric permittivity was obtained within a moisture content range of 0.7672 to 0.9363 with fitting coefficient R^2=0.9470. This is in sharp contrast with the linear model obtained by Parsekian and Slater (2011) with R^2=0.928 for peat soil collected at Minnesota, Northern USA and logarithmic model obtained by Pumpanen and Ilveniemi (2005) with R^2=0.968 for peat deposit in southern Finland. It therefore implies that both the nature of $\varepsilon_r : \theta$ equation and the fitting coefficients vary with location due to the variation in vegetation cover and therefore reaffirmed the need for site-specific calibration with respect to a given locality.

It could however be noted that there are several factors that contribute to the magnitude of the dielectric constant of materials which might likely affect the accuracy of the predicting equation. The most significant of all the factors is the operation frequency (Wagner *et al*, 2007). Other factors are temperature and bulk density which are taken care-off by performing the experiment with undisturbed soil specimen in a constant laboratory temperature condition.

Dielectric permittivity is a complex frequency-dependent parameter which is related to energy loss due to relaxation mechanism in the vicinity of EM fields. Polarization due to the reorientation of dipolar molecules under the influence of externally applied EM field occurs at different scales for different signal frequencies. The frequency dependence of dielectric constant is described by Debye theory, of relaxation (Santos *et al*, 2009). The theory, which described the behavior of electric dipole when excited by signal at different frequencies, gives the relationship between the real (measured) component of dielectric permittivity of water and frequency of the applied signal. According to the relationship, the real component of dielectric permittivity is nearly constant at frequencies lower than 1.0GHz. Topp *et al* (1980) also observed that at frequency below 1.0GHz to 1.5GHz, . ε_r is only weakly frequency dependant. At frequency above 1.5 to 2GHz however, ε_r decreases rapidly with increasing frequency. This is due to the fact that within the frequency range of 1MHz to 1GHz, the dipolar molecules of water are the largest contributors to the effective dielectric permittivity of peat soil and ε_r is therefore nearly constant within the range.

The plots of the laboratory measurements of the dielectric constant and water content of the sampled cores shown in Fig.5 indicate corresponding variation of the two parameters with depth in most of the points. Deviation is however recorded at a depth of 1.5m in which a slight response of the water content is recorded with respect to significant change in the dielectric permittivity recorded at the depth. This could possibly be due to the occurrence of highly decomposed peat deposit associated with low water holding capacity at the region (Huat *et al*., 2011).

The intercept of Fig. 3 (8.E-13F/m) gives the error readings in capacitance measurement which was subtracted from the measured capacitance. It is however observed that despite this correction, the designed capacitor over estimated the dielectric permittivity of air to a mean value of $4.2889 \times 10^{-11} F/m$ compared to a literature value of $8.8542 \times 10^{-12} F/m$. This will by no means affect the validity of the result as the experiment is designed to measure the relative dielectric permittivity, a ratio of permittivity of the soil sample to that of the free space. The systematic or zero error of the instrument therefore cancels out as long as the calibration remains for relative dielectric permittivity measurement.

The model equation obtained was based on relatively small range of water content variation (0.7672 to 0.9363) while it is obviously known that peat water content could be as high as 700% (Huat *et al*, 2011). The range of the water content in the experimental data was constrained by the fact that at no point is the peat found to have water content less 0.7672. This fact coupled with the impracticability of collecting undisturbed peat sample with water content at or above 100% are constrains that restrict the range of the model equation. We tried to predict the water content of the deposit beyond this range with the model equation based on the obtained radar velocity values from the GPR data. The accuracy of the water content beyond this range could however not be ascertained. It is however observed from the box plot of the water content distribution (Fig. 8) that the upper and lower quartiles of the distribution are about 1.000 and 0.7000 respectively while the lowest non outlier range of 0.600 was recorded at profile 2. Water contents recorded beyond these ranges are outliers that appear to deviate markedly from the main distributions. These imply that the model is capable of predicting the water content of the peat within the quartile range with reasonable level of accuracy.

Water content within a range of 0.2033 to 2.156 was obtained across all the profiles within the covered depth range of 3.5m. With a mean value of 1.1437 and a standard deviation of 0.5327, the result is reasonably within the range of the deposit's water contents obtained by Idi and Kamarudin (2012) using the complex refractive index (CRIM) model. The high water content of the deposit was also observed earlier by Huat (2004) who states that the natural water content of the peat deposit of the coastal area of western Johor could be as high as 200-700%.

The box plot shown in Fig. 8 gives the distribution of water content of the subsurface relative to the four scanned transects. According to the plot, a wider range of water contents are recorded across profile 3 with extremes at about 0.2 to 2.7. Larger magnitude of water contents are however recorded across profile 4 based on the relative positions of the medians and the quartile ranges. The nearly constant values of the water content at depth range of 0.5 to 2.5m (mean of 0.9091 with a variance of 0.000184) indicates that the peat soil is nearly homogeneous within the range. It could also be as a result of the fact that the deposit between the depth ranges is under waterlogged condition as observed. The major variation in the peat composition could be attributed to the variation in water content as indicated by the topsoil. It could however be observed from Figure 8 that the vertical distribution of water content across the profiles is not linear. This could be as a result of the spatial variation in the rate of decomposition of the deposit. It may also be as a result of the presence of biogenic gas, a product of anaerobic processes that occur due to microbial activities within the pore space. The gases where they occur displace the water in the pore space so that under saturation condition, the pore spaces are filled water and the gas.

Even though the model equation is site-specific due to the complex changes in peat's composition with climate and vegetation cover, the equation could be applicable to tropical peatlands of similar nature with the same type of peat plant-forming community. This model could therefore serves as a means of water content estimation in southwest Malaysian peatland and any other peat deposit of similar vegetation cover.

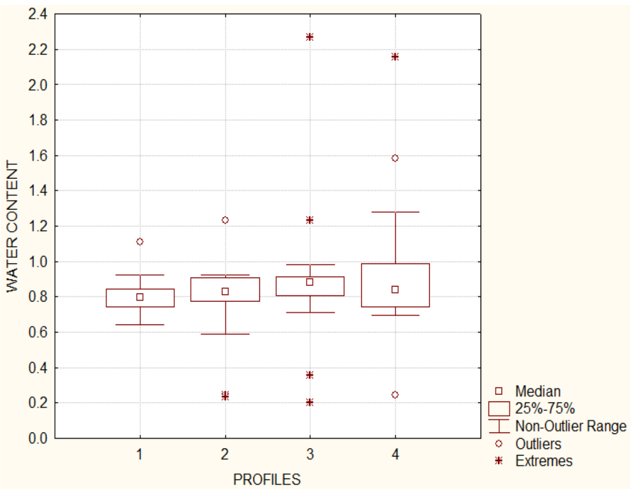


Figure 8: Box plot of the spatial distribution of water content obtained from the four transects.

CONCLUSIONS

In this work, modeling of dielectric constant with water content with respect to Pontian peat deposit was successfully accomplished leading to an empirical equation that predicts the water content of the deposit for a given dielectric permittivity value. Various model equations that are found applicable to peat based on previous works were tried. With a fitting coefficient R^2 =0.947, third order polynomial model equivalent to Topp's equation gives the best fitting for the $\varepsilon_r : \theta$ relationship. The model equation can accurately predicts water content within a range of 0.7672 to 0.9363 being the minimum and maximum water contents obtained from the core samples used. The dielectric constants obtained from radar velocity measurements however suggest a wider range of water content. Water content beyond the model range is however found to be statistically within the outliers and extremes as such cases are rare with low frequency of occurrence within the study area. Thus for wider and accurate application, further study on the model is needed with the aim of widening the scope of the water content range used for this work. The empirical equation could however served as preliminary reconnaissance survey tool for water content and other related parameters such as special distribution of free-phase biogenic gas content and cation content of the deposit noninversibly within the vedose zone of the deposit.

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