Complexity Analysis of Peat Soil Density Distribution

Joko Sampurno[1, *)], Irfana Diah Faryuni[1], Fourier Dzar Eljabbar Latief[2], Wahyu Srigutomo[2]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences, Tanjungpura University

[2]Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia

[*)]Corresponding author: jokosampurno@physics.untan.ac.id

Abstract. The distributions of peat soil density have been identified using fractal analysis method. The study was conducted on 5 peat soil samples taken from a ground field in Pontianak, West Kalimantan, at the coordinates (0 ° 4 '2:27 "S, 109 ° 18' 48.59" E). In this study, we used micro computerized tomography (μCT Scanner) at 9.41 micro meter per pixel resolution under peat soil samples to provide 2-D high-resolution images L1-L5 (200   200 pixels) that were used to detect the distribution of peat soil density. The method for determining the fractal dimension and intercept was the 2-D Fourier analysis method. The method was used to obtain the log log-plot of magnitude with frequency. Fractal dimension was obtained from the straight regression line that interpolated the points in the interval with the largest coefficient determination. Intercept defined by the point of intersection on the -axis. The conclusion was that the distributions of peat soil density showing the fractal behaviour with the heterogeneity of the samples from the highest to the lowest were L5, L1, L4, L3 and L2. Meanwhile, the range of density values of the samples from the highest to the lowest was L3, L2, L4, L5 and L1. The study also concluded that the behaviour of the distribution of peat soil density was a weakly anisotropic.

1. Introduction

Peats were formed as the result of the accumulation of the organic residues, particularly in high rainfall area which makes the rate of organic residues decomposition faster [1]. Pontianak is a city where the soil structure is dominated by peat. Information on the physical parameter such as the distribution of peat soil density is necessary to understand the physical properties of peat soil and for various purposes.

The literature shows that fractal geometry has been successfully used to interpret the soil structure, such as image analysis of soil in gray scale and binary scale [2-3], mapping the fractal dimension of soil in agricultural land with GPR [4], analysis of reliefs at the microscopic scale of the cross section of the soil [5] and a cross-sectional analysis of the level of heterogeneity [6].

The objectives of the present paper are to observe the level of complexity and the behavior of the distribution of peat soil density with fractal characterization. The method of determining the fractal dimension was 2D Fourier analysis method, to obtain the log-log plot of magnitude with frequency

and defining the dimension itself as the straight regression line that interpolated the points in the interval with the largest coefficient of determination.

2. Method

The study was conducted on 5 peat soil samples taken from a ground field in Pontianak, West Kalimantan, precisely at the coordinates (0 ° 4 '2:27 "S, 109 ° 18' 48.59" E). The samples were then dried to remove water content. Then we used micro computerized tomography (µCT Scanner), with resolution of 9.41 micrometers per pixel, under peat soil samples to provide 2-D gray scale high-resolution images L1-L5 (200   200 pixels) that were used to analyze the distribution of peat soil density (Figure 1). The images are then processed with a 2-D Fourier analysis method to determining the fractal dimension and the intercept. Both of these parameters obtained from the curve of the log-log plot of magnitude vs. frequency. This method has been developed by Salisbury, et al. [7].
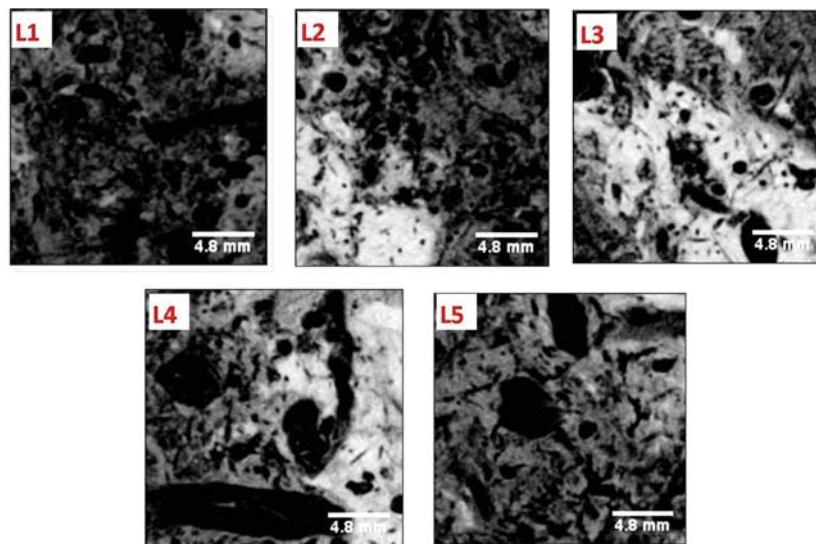

Figure 1. 2D Images of peats in gray scale

The basic theory of 2D Fourier analysis is a generalization of the one-dimensional case. The magnitude of each Fourier coefficients will show how significant the contribution of each frequency. Power spectrum density (PSD) of the 2D Fourier Transformation can be used to establish the relative significance of the measurement at each frequency. In the discrete form, PSD can be determined by Equation 1 [8]:

$$P\left(\omega_1,\omega_2\right) = \frac{mn\left(a_{pq}^2 + ib_{pq}^2\right)}{\sum_{x=1}^{m}\sum_{y=1}^{n}z_{xy}^2} \tag{1}$$

Where $P\left(\omega_1,\omega_2\right)$ represents *PSD*, z_{xy} represents the elevation of a point in the x-y plane and a, b are Fourier coefficients.

In this method, the distribution of pixels in a space domain was transformed into the frequency domain. The transformation was to get the PSD. If the images behave as fractal, then the plot of log (magnitude2) vs. log (frequency) will generate a linear curve. Fractal dimension was obtained from the slope of the curve. Intercept obtained from the point of intersection on the y-axis. Fractal dimension calculated from the slope by equation [9]:

$$D = \frac{6 + \beta}{2} \qquad\qquad (2)$$

Where D represents the fractal dimension and β represents slope.

   Magnitude distribution, as the result of 2D Fourier Transformation, will be divided proportionally into 24 groups based on the phase angle. Dimensions and Intercepts for each group will be plotted by using Rose Plot. Based on the curve of Rose Plot, it can be determined whether the surface of the peat soil is isotropic, weak anisotropic or strong anisotropic [9].

3. Result and Discussion

Figure 2 shows the log-log plot of magnitude vs. frequency for each sample which was created based on the 2-D Fourier analysis method. Figure 2 shows that the curve for all of the samples represents as linear curve. From the shape of the curve it can be concluded that all density distributions of peat samples, which were observed, behave as a fractal.
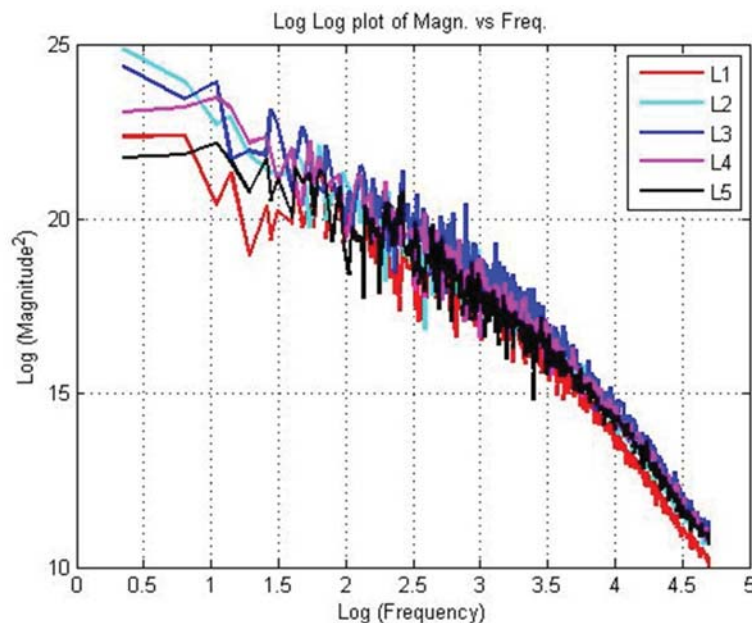

Figure 2. Log-log plot magnitude vs. frequency

   Table 1 gives the values of fractal dimension (D) and intercept of the samples is 1.26 to 1.37 and 26.91 to 28.45.

Table 1. Fractal dimension and intercept of samples

	L1	L2	L3	L4	L5
Fractal Dimension	1.34	1.26	1.26	1.28	1.37
Intercept	26.91	28.16	28.45	28.04	27.08

   Table 1 shows that all of the samples had low density variations, the most heterogeneous sample was L5 because it had the largest dimension (D =1.37), whereas the lowest sample density variation were L2 and L3 because both of them had the smallest dimensions (D = 1.26), its suitable with the

statement of the Xie et.al [10] that the fractal dimension represent the level of heterogeneity of a cross-section.

Specifically, for all of the samples, the values of the fractal dimensions were almost similar. It was mean that the level of heterogeneity for all samples was almost similar too. The level of heterogeneity of peat samples from the highest to the lowest was L5, L1, L4, L3 and L2 respectively.

Russ [9] stated that the Slope in 2D Fourier analysis only represents the heterogeneity of spatial variation of a surface. Meanwhile, the heterogeneity of magnitude range represents by intercept. From Table 1 it can be seen that L3 had the highest intercept followed by L2, L4, L5 and L1 respectively. This means that L3 had the highest range of density values while the L1 has the smallest range. However, since the intercept of all samples was very close, it can also be understood that the range of density values for all samples were almost similar.

Qualitatively, the behavior of the density distribution of peat can be understood from the shape of Rose Plots of slope and intercept (Figure 3).
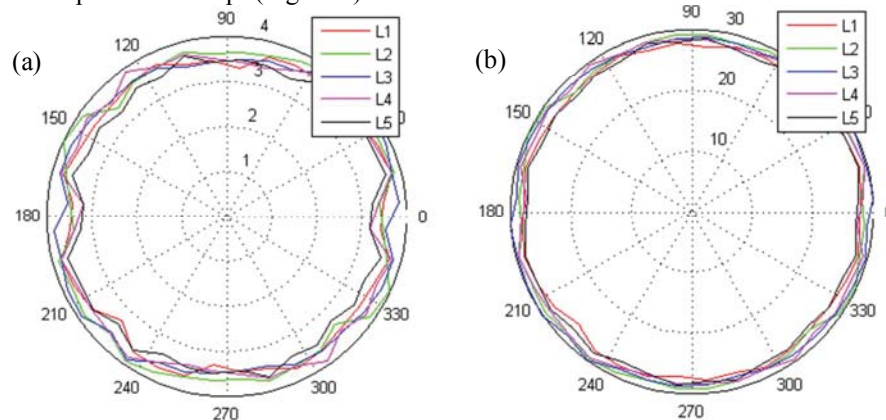

Figure 3. (a) Rose plot of slopes, (b) Rose plot of intercepts

Figure 3a shows that the fractal dimensions of all samples depend on the phase angles. It means that the density distributions of all samples (L1 - L5) were anisotropic. Figure 3b confirms that intercept values of all samples did not depend on the phase angles (intercept value was almost similar in all directions of measurement). It means that qualitatively the behavior of the density distribution of peat was weak anisotropic.

4. Conclusion
From this study, it can be concluded that the complexity of density distributions of the peat samples behaves as a fractal. The level of heterogeneity of peat samples from the highest to the lowest was L5, L1, L4, L3 and L2 respectively. The range of density values of peat samples from the highest to the lowest was L3, L2, L4, L5 and L1 respectively. Qualitatively the behavior of the density distribution of peat was weak anisotropic.

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