Characterization the geometry of the peat soil of Pontianak using fractal method

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Abstract. Characterization of the microscopic pore structure of various types of peat soil of Pontianak has been done. The data consist of three types of peat (Sapric, Hemic, and Fibric), in which every type consists of three samples. The characterization was done in macro and micro level. At the macro level, samples were measured their physical properties namely bulk density, porosity and particle size distribution. In the micro level, samples were scanned using Micro-CT Scanner to reconstruct their 3D microstructure imagery. The images then analyzed using the fractal method to obtain their regularity level. The result shows that the regularity of pore distribution of each sample was varied. Yet, based on their types, Hemic has the most irregular pore size distribution.

1. Introduction

Pontianak is the capital of West Kalimantan Province of Indonesia, which has area 107.8 km² [1]. This city is located in the Kapuas river delta region. The land of the city is dominated by mud, gravel, sand, and plant debris [2]. The area of Pontianak is mostly covered by peat soil, which occupies 51.42% of the total area of the city [3].

Peat soil is a type of soil that rich in organic content [4,5,6]. The organic content of peat soil can reach more than 75% [5]. Peat soil can also be defined as fibrous soil resulting from decomposition and decay of microscopic and microscopic flakes of plants [7]. Because it consists of weathering fibers, this causes the porosity of the soil to be generally high in size [8].

Based on the level of organic maturity, peat soil can be classified into three types: Fibric, Hemic and Saprik [9]. The maturity level of peat soil is based on the content of organic fibers. Peat soil is classified as Fibric if the fiber content is greater than 67%, classified as Hemic if its fiber content between 33% - 67% and classified as Sapric if its fiber content less than 33% [9]. Fibric is a type of peat that most of its material has not decomposed and generally reddish brown. Hemic is a peat that about half its material has decomposed and generally dark and reddish. Sapric is peat which most of its material has been decomposed, normally has a darker color than the other types, and it contains the highest organic element than the other [10].

The previous works show that fractal geometry has been successfully used to interpret the 2D image of peat soil structure [11-13]. Fractal geometry is a geometry that constructed by repetition and sequence of simple geometric shapes that are replicated repeatedly and combined with each other on a
variety of scales. Fractal geometry has self-similarity characteristic which shows that fractal consist of parts that are similar in shape to each other.

In this study, the physical properties of peat soil are observed based on its type. The objective of the present study is to compare the geometry of 3 types of peat soil of Pontianak using fractal method. For that purpose, analysis of peat samples was conducted in two levels, macroscopically and microscopically. At macroscopic level observation, the analysis was done on two parameters namely bulk density and porosity. While at the microscopic level, the analysis process is performed on the 3D image of peat soil that is reconstructed using Micro-CT Scanner. Furthermore, fractal analysis was conducted in order to compare the physical properties of peat soil with its pore structure.

2. Method

Peat soil samples were taken from three locations (L, P and S). The first location (L) is located at coordinates 00° 01’ 29.2” N and 109° 22’ 26.4” E. The second location (P) is located at coordinates 00° 04’ 08.7” S and 109° 19’ 19.5” E. The third location (S) is located at coordinates 00° 04’ 26.2” S and 109° 20’ 18.9” E (See Figure 1).

For every location (L, P and S), three samples were taken from different depths. The number of peat soil samples were taken is 9 (3 samples from each location). Samples are labeled according to the location and the type of the peat soil. For example, sample from location L is labeled with L1 for Sapric, L2 for Hemic and L3 for Fibric. This procedure is also carried out on samples from P and S sites. The depth of all peat soil samples is presented in Table 1.

| Location | Sample code | Depth (cm) | Type   |
|----------|-------------|------------|--------|
| L        | L1          | 0 – 10     | Sapric |
|          | L2          | 30 – 40    | Hemic  |
|          | L3          | 70 – 80    | Fibric |
| P        | P1          | 10 – 20    | Sapric |
|          | P2          | 40 – 50    | Hemic  |
|          | P3          | 90 – 100   | Fibric |
| S        | S1          | 10 – 20    | Sapric |

Figure 1. Location of peat soil samples[14]
2.1. Macroscopic Level
At the macroscopic level, laboratory tests are performed to determine the porosity and the bulk density of the peat. To determine the bulk density of the soil, firstly the dry weight of the sample was measured. Then, the bulk density is determined from the ratio between dry weight and sample volume. The volume is calculated using the cylindrical volume equation \( \pi r^2 t \), where \( r \) is the radius and \( t \) is the height of the sample tube.

Porosity (\( \phi \)) is the ratio between empty space (including pore space, fractures, cracks, etc.) in the sample and total sample space. Thus, porosity (\( \phi \)) is calculated based on the volume of pore space (\( V_p \)) and the total volume of sample (\( V_t \)) using the following equation:

\[
\phi = \frac{V_p}{V_t} \times 100\%
\] (1)

2.2. Microscopic Level
At the microscopic level, the sample is reconstructed into a digital image. Digital images are reconstructed using Micro-CT Scanner Skyccan 1173. First, peat soil samples are made in the cubes form (2cm x 2cm x 2cm). Then, the sample is scanned to produce three-dimensional images (3D) which has a pixel size 300x300x300 pixels\(^3\). Figure 2 shows the result of peat soil reconstruction in RGB for each sample with image resolution 28 \( \mu \)m.

![Figure 2. The Results of peat reconstruction in 28 \( \mu \)m resolution (a) Sapric; (b) Hemic and (c) Fibric.](image)

Furthermore, the image is transformed into a binary image to separate between the pore and the matrix. Binary image is then analysed using software CTAn [15] to calculate the pore size distribution and analysed using fractal method to characterize the regularity level of soil pore structure. The calculation of pore size distribution of the peat, which using CTAn, has been done in 2 stages [16]. Firstly, a “skeletonisation” is performed to recognize the average axis of all structures. Next, a “sphere-fitting” estimation is made for all the voxels lying along the axis.

2.3 Fractal Analysis
Fractal dimension is calculated using Box-Counting method. In the Box-Counting method, the fractal dimension of a 3D image is calculated by [17]:

\[
D = \lim_{r \to 0} \frac{\log N(r)}{\log \left( \frac{1}{r} \right)}
\] (2)
Where $D$ is fractal dimension, $N (r)$ is the number of grid boxes which contain pore, and $r$ is the size of the box.

3. Result and Discussion
The result of the measurement of all samples shows that the bulk density of Pontianak peat is varied. At location L, the bulk density of the peat ranges from 0.10 g/cm$^3$ to 0.23 g/cm$^3$. At location P, the bulk density of peat ranges from 0.08 g/cm$^3$ to 0.21 g/cm$^3$. At location S, the bulk density of the peat ranges from 0.06 g/cm$^3$ to 0.20 g/cm$^3$.

Yet, commonly the bulk density of the peat depends on its maturity and its compaction. It can be seen at the Table 2 that the bulk density of peat from the largest to the smallest are Sapric, Hemic and Fibric respectively. The more mature the peat soil, the greater the bulk density. However, in general the bulk density of peat soil is relatively low. This causes the bearing capacity of the soil is also low.

From the Table 2, it can be also seen that porosity is affected by maturity and compaction processes. The less mature of the peat, the greater of its porosity. On the other hand, the greater of the bulk density, the smaller of its porosity and vice versa. Peat porosity from the smallest to the largest is shown by Saprik, Hemic and Fibrik respectively. The porosity of all peat samples ranged from 77.23% to 95.18%.

| Sample Code | Type  | Bulk density (g/cm$^3$) | porosity (%) |
|-------------|-------|------------------------|--------------|
| L1          | Sapric| 0.23                   | 77.23        |
| L2          | Hemic | 0.13                   | 88.85        |
| L3          | Fibric| 0.10                   | 92.12        |
| P1          | Sapric| 0.21                   | 79.38        |
| P2          | Hemic | 0.11                   | 90.08        |
| P3          | Fibric| 0.08                   | 93.62        |
| S1          | Sapric| 0.20                   | 80.20        |
| S2          | Hemic | 0.11                   | 90.21        |
| S3          | Fibric| 0.06                   | 95.18        |

Next, peat samples were reconstructed using Micro-CT Scanner SkyScan 1173. In the scanning process, the scanning parameters used were: current source: 50 μA, voltage source: 55 KV, illumination time: 500 ms, and resolution: 28 μm. The reconstruction result is displayed in 3D grayscale image, which has a size of 300x300x300 pixels$^3$. Figure 3-5 show the reconstruction results for all peat samples, with white as granules.

Figure 3. 3D Reconstruction of peat samples from location L, where: (a) Sapric; (b) Hemic; and (c) Fibric
Figure 4. 3D Reconstruction of peat samples from location P, where: (a) Sapric; (b) Hemic; and (c) Fibric

Figure 5. 3D Reconstruction of peat samples from location S, where: (a) Sapric; (b) Hemic; and (c) Fibric

Table 3. Fractal Dimension of all samples.

| Sample Code | Type    | Pore size (pixel) | Fractal Dimension |
|-------------|---------|-------------------|-------------------|
| L1          | Sapric  | 2 - 34            | 2.90              |
| L2          | Hemic   | 2 - 66            | 2.73              |
| L3          | Fibric  | 2 - 70            | 2.70              |
| P1          | Sapric  | 2 – 76            | 2.69              |
| P2          | Hemic   | 2 - 84            | 2.58              |
| P3          | Fibric  | 2 - 132           | 2.69              |
| S1          | Sapric  | 2 – 56            | 2.58              |
| S2          | Hemic   | 2 - 50            | 2.15              |
| S3          | Fibric  | 2 - 100           | 2.76              |

From Table 3, it can be seen that the fractal dimension of the 3D image of Pontianak peat ranges from 2.15 to 2.90. The fractal dimension closer to three indicates that the pore distribution is more regularly, and vice versa. According to the Table 3, Hemic has the smallest fractal dimension when compared to Sapric and Fibric. It indicates that the distribution of Hemic pore is the most irregular when compared with other peat types. This condition is because Hemic is a kind of semi-mature peat, which means some of its material has been decomposed and some has not. This causes the distribution of pore size is more varied.
The results of digital image reconstruction can also be used to calculate the peat pore size distribution. Figure 6 - 8 show the results of the calculation. From the figure 6-8, it can be seen that the largest pore size interval belongs to Fibric, followed by Hemic and Sapric. Sapric has the smallest pore size interval because it is the most decomposed and most mature type of peat. So that, most of its pore has almost similar size.

![Figure 6. The distribution of peat pore size at location L](image)

![Figure 7. The distribution of peat pore size at location P](image)
4. Conclusion
From the data above, it can be concluded that the porosity of all types of samples from the highest to the lowest belongs to Fibric, Hemic, and Sapric respectively. Next, the bulk density of all types of samples from the highest to the lowest belongs to Sapric, Hemic, and Fibric respectively. Similar to that, the range of pore size distribution of all types of samples from the widest to the narrowest also belongs to Sapric, Hemic, and Fibric respectively. Based on their fractal dimension, the regularity level of pore distribution of each type sample depends on the location. Yet, Hemic almost has the most irregular pore size distribution.

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Figure 8. The distribution of peat pore size at location S
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