Fractal analysis of land surface temperature for geothermal and non-geothermal sites characterization

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Abstract: This study discusses fractal analysis for characterization both geothermal and non-geothermal surface temperature. The data were obtained from Landsat-8 satellite imagery and analyzed by using Fractal method to produce complexity parameters (Dimension, Intercept, and Lacunarity). The result shows that the fractal method can be applied successfully to characterize and distinguish the pattern both these surface temperatures. The plots of all parameters exhibit that the geothermal surface has a convergence pattern, while the non-geothermal area has a divergence pattern.

1. Introduction
One of the most promising technologies to be applied in geothermal exploration is remote sensing [1]. The application of remote sensing for geothermal exploration was initiated by Huntington [2], Rowan [3], Mars and Rowan [4], Carranza et al. [5], Bedini [6], Mars and Rowan [7], Kruse [8], and van der Meer et al. [1]. This method is promoted because of the abundance of remote sensing data sources are available for free and it allows time-consuming monitoring campaign [9].

Remote sensing is a method to photograph the condition of the land surface based on the satellite images [10]. This method has applied in many kinds of research [11][12][13]. The newest satellite, which performs this function, is Landsat-8 [13]. Landsat 8 was launched by NASA on April 11, 2013. The satellite is equipped with two main sensors, including Operational Land Imager (OLI) to map the contours of the land surface and the Thermal Infrared Sensor (TIRS) to map the temperature of Land surface [13].

One of the important issue in remote sensing technology for geoscience is how to analyze and interpreted the images [13]. As the solution, one of the promising methods to solve the problem is Fractal. The fractal method has been applied in many Geoscience studies due to its capability to solve many geological problems and its capability to quantify the complexity parameters of an object [14] [15] [16] [17].

In this study, Fractal method has been applied to analyze the remote sensing imagery. The aim of the study is to characterize the land surface temperature of the geothermal site and compares it to the non-geothermal surface. This characterization uses some complexity parameters, namely: Dimension, Intercept, and Lacunarity.
2. Methodology

2.1. Data Collection
Twenty raw imageries data of Landsat-8 satellite were obtained from the United States Geological Survey (USGS) website [18] (Fig. 1a) and separated into two groups (10 imageries from the geothermal area and 10 imageries from the non-geothermal area). Both geothermal and non-geothermal locations were chosen based on the report of Ministry of Energy and Mineral Resources of the Republic of Indonesia [19]. Furthermore, these data were cropped and corrected using the radiometric correction in order to obtain real land surface temperature (Fig. 1b).

![Figure 1. (a) raw imagery data downloaded from USGS[18]; (b) Land Surface Temperature after radiometric correction](image)

2.2. Fractal Analysis
In the 2D Fourier Transform method, a data in space domain was transformed into the frequency domain to produce Power Spectrum Density (PSD). In the discrete form, the PSD of the 2D Fourier Transformation can be obtained by [20]:

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

Where P is the symbol of the PSD, Zxy is the pixel value of a point in the x-y plane, a and b represent the Fourier coefficients.

In order to obtain fractal parameters, The PSD profile is plotted using Log-Log Plot to produce a linear curve (Fig. 2). According to the curve, Intercept and Dimension can be calculated. The point of
intersection on the y-axis is considered as Intercept while Fractal dimension is obtained from the slope by [21]:

\[ D = \frac{6 + \beta}{2} \]  

(2)

Where D is the Fractal Dimension and \( \beta \) is the slope.

![Figure 2. Log Magnitude vs. Frequency for Dimension and Intercept calculation](image)

2.3. Lacunarity Analysis

Lacunarity was introduced to distinguish the fractal objects that have a different appearance but have same Dimensions [22] [23]. This parameter can be used to complement the Dimension. In texture analysis, high Lacunarity means the pattern of the texture is heterogeneous, while low Lacunarity means the texture pattern is homogeneous [23,24]. Heterogeneous means that the image pixels spread in wide ranges and surrounded by large gaps [24].

Gliding-box algorithm which created by Allain and Cloitre [25] is one of the simple method to calculate Lacunarity from a binary image. This algorithm consists of several steps. First, the image is covered by a box which size \( r \times r \). Next, the box then glides over the image from upper left to the right to obtain the number of occupied mass \( S \). Lacunarity of an image can be calculated using [25]:

\[ \Lambda(r) = \frac{z^{(2)}}{z^{(1)}} \]  

(3)

Where \( z^{(1)} \) and \( z^{(2)} \) are the first and the second moment which obtained from [25]:

\[ z^{(1)} = \sum SQ(S,r) \]  

(4)

and,

\[ z^{(2)} = \sum S^2 Q(S,r) \]  

(5)

In the Eq. 4 and Eq. 5, Q is probability distribution which obtained from [25]:
\[ Q(S, r) = \frac{n(S, r)}{N(r)} \]  

(6)

where, \( n(S, r) \) is total number of box which have size \( r \) and containing \( S \) and \( N(r) \) is number of all boxes that have size \( r \). \( N(r) \) is calculated by [25]:

\[ N(r) = (M - r + 1)^2 \]  

(7)

where, \( M \) is the size of the image.

3. Result And Discussion
The fractal parameters (Dimension, Intercept, and Lacunarity) both the geothermal (Table 1) and non-geothermal (Table 2) areas were demonstrated.

| Table 1. Fractal parameters of geothermal area |
|---|---|---|---|
| No | Location Name | Dimension | Intercept | Lacunarity |
|---|---|---|---|---|
| 1 | Jaboi | 1.484 | 24.661 | 0.222 |
| 2 | Muaralaboh | 1.512 | 26.121 | 0.373 |
| 3 | Rajabasa | 1.469 | 24.968 | 0.139 |
| 4 | Rantau Dadap | 1.442 | 26.166 | 0.431 |
| 5 | Sarulla 3 (Sibual-Buali) | 1.487 | 24.947 | 0.075 |
| 6 | Seulawah Agam | 1.562 | 24.686 | 0.345 |
| 7 | Sorik Merapi (Roboran - Dolok) | 1.484 | 24.561 | 0.118 |
| 8 | Sorik Merapi (Sampuraga) | 1.533 | 24.707 | 0.186 |
| 9 | Tampomas | 1.433 | 25.944 | 0.199 |
| 10 | Wayang Windu | 1.487 | 25.516 | 0.117 |

The highest Fractal Dimension for geothermal area is 1.562, while the lowest is 1.433. Intercepts of this category are spread between 24.561 and 26.166. Finally, Lacunarity of this group extend from 0.075 to 0.431.

| Table 2. Fractal parameters of non-geothermal area |
|---|---|---|---|
| No | Location Name | Dimension | Intercept | Lacunarity |
|---|---|---|---|---|
| 1 | Aseupan | 1.305 | 27.806 | 0.155 |
| 2 | Cikuray | 1.34 | 27.13 | 0.305 |
| 3 | Ciremai | 1.338 | 26.634 | 0.613 |
| 4 | Gunung Argapura | 1.132 | 29.157 | 0.571 |
| 5 | Gunung Arjuna | 1.363 | 27.041 | 0.147 |
| 6 | Gunung Kinabalu | 1.327 | 27.584 | 0.144 |
| 7 | Puncak Jaya | 1.324 | 27.46 | 0.217 |
| 8 | Puncak Trikora | 1.347 | 27.591 | 0.316 |
| 9 | Sumbing | 1.163 | 29.255 | 0.209 |
| 10 | Gunung Wilis | 1.429 | 26.683 | 0.223 |
The highest Fractal Dimension for non-geothermal area is 1.429, while the lowest is 1.132. Furthermore, Intercepts of this category expand from 26.634 to 29.255. Lastly, Lacunarity of this group spreads between 0.144 and 0.613.

From both Table 1 and 2, we can obtain the relation between Dimension and Intercept, Dimension and Lacunarity, and also Intercept and Lacunarity as shown in Fig. 3, 4, and 5 respectively. Then a combination of these three parameters is given in Fig.6.

**Figure 3. Fractal Dimension vs. Intercept**

From Fig. 3, it can be seen clearly that plot of fractal dimension due to intercept can distinguish between geothermal and non-geothermal surface temperature. Blue dots in Fig. 2 indicate the geothermal area while red squares represent the non-geothermal area. Next, it can be analysed that the Dimension-Intercept phase of geothermal location tends to converge in one zone; on the other hand, Dimension-Intercept phase of non-geothermal location are spread out widely. However, this schema is successful in distinguishing geothermal and non-geothermal surface temperature.

**Figure 4. Fractal Dimension vs. Lacunarity**
Fig. 4 shows the scattering of Dimension vs. Lacunarity plots. From the graph, it can be shown that this scattering can differentiate the geothermal area and the other one, although not all data are separated as well. From the figure, it can be seen that geothermal scattering pattern tends to converge while the non-geothermal pattern diverges. This pattern is similar to the plot of Dimension vs. Intercept.

![Graph showing scattering of Dimension vs. Lacunarity](image)

**Figure 5. Intercept vs. Lacunarity**

Similar to the previous graph, the plot of Intercept vs. Lacunarity is also successful in discriminating the pattern of the geothermal area and non-geothermal area. In this graph, the scattering plots of the geothermal area tend to behave nearer together while plots of non-geothermal area tend to spread widely. Thus, this scheme can also be used to characterize the geothermal surface area.

![Graph showing 3D plot of all parameters](image)

**Figure 6. 3D Plot of all parameters**
Finally, we combine all parameters from the Table 1 and 2 to produce 3D Plotting as shown in Fig. 6. The figure shows that a combination of all parameters can be used to separate the pattern of geothermal surface temperature with the other one. This combination also produces the same characteristic with the previous graphs, which the geothermal area produces a huddled pattern. On the other hand, the non-geothermal area produces the spread widely pattern.

While in the previous study, the fractal method has successfully characterized the sea floor [12], characterize the tropospheric ozone [14] and classify the plant leaf [26], in this study we found that fractal has been also successfully characterize the geothermal and non-geothermal sites. Based on the fractal parameters which have been found in this study, one can move forward to apply this method in a localized area in order to find a reservoir spot. The localized area can be divided into pieces. Fractal analysis can be applied to every piece of the study area in order to distinguish between a reservoir spot and its surroundings.

4. Conclusion

This study has demonstrated the using of Fractal analysis (Dimension, Intercept, and Lacunarity) for characterizing the surface temperature of geothermal and non-geothermal areas with different pattern. The plots of all parameters show that the geothermal area has a convergence pattern while the non-geothermal area has a divergence pattern.

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