Article

Identifying Peat Soil Layers in the South Kalimantan, Indonesia Using K-Means Clustering

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Abstract: Various type of soils have been identified based on their electrical and magnetic properties, especially with regards to peat soils. Peat soils are commonly considered as partly decomposed vegetation. In this study, electrical and magnetic properties have been used in K-means clustering to identify layers of peat soils. K-means clustering is a partitioning method that treats observations in the data. Data cores were obtained at every centimeter and examined for their electrical conductivity (σ) and magnetic susceptibility (χ_m) properties. A 291 cm core was obtained at Tegal Arum Village in South Kalimantan, Indonesia. The K-means clustering results indicate two different layers at 148 cm, and this is supported by loss on ignition (LOI) measurements. In the first layers, a 87.65% LOI was found associated with peat soils (above 248 cm). Whereas, in the second layers, there was a 26.11% LOI associated with mineral soils (below 248 cm). The results of this study using K-means clustering can be used to delineate soil layers.

Keywords: peat; electrical conductivity; magnetic susceptibility; K-means clustering; loss on ignition (LOI); organic soils; mineral soils; Indonesia

1. Introduction

The study of peat soil has developed rapidly to be able to determine carbon emissions, especially in the peatlands of Indonesia [1–7]. A large amount of carbon emission is produced by peatlands, which is mostly determined by the depth or the thickness of the peat [1,2,8]. Accurate information parameters on the depth and the thickness of the peat must be used in this research. Determination of depth or thickness of peat soil is usually done by direct measurement [9] or by using the geophysical method [1,9,10].

Furthermore, the characteristics of peat or organic soil are also influenced by the electrical conductivity (σ) properties and susceptibility magnetic (χ_m) properties. The σ properties of the soil are also influenced by organic matter content, water content, and clay content [11,12]. The more organic contents in the peat, the higher the σ [13–15]. In magnetism, the χ_m properties of the soil also has a correlation with organic content: χ_m decreases as organic matter content increases. This is the same as research in eroded areas in Sakatchewan, Canada [16]. In the studies of land conducted by Hanesch and Scholger [17] and Hanesch et.al [18], it was concluded that soil with more organic content had a smaller χ_m . This is the same result as in the study of Hošek et.al [19]. Rothwell and Lindsay [20] charted the Alport More area in the UK in the terms of the relationship between peatland and χ_m values. Their results indicated that the presence of peat or organic soil was characterized by lower χ_m values.

The cluster K-means method is the most effective for clustering, and it can be applied in various studies [21]. The cluster K-means method has been applied to analyze topography and soil data [22], water classification [23], transportation [24], electricity consumption [25–27], tumor areas in the field of medicine [28], and validate the existence of oil palm plantations [29]. K-means clustering determines the landslide boundary in the Three Gorges area in China [30]. The cluster means method divides the segments based on similar data. In this study, it is expected that data collected from one layer will be the same, while the data will differ from other layers. The parameters σ and χ_m are used to analyze and characterize the soil effectively. In this study, K-means clustering determines the boundary peat soil layer based on electrical and magnetism properties.

2. Materials and Methods

The study area is located at the Tegal Arum Village, 31 km from Southeast Banjarmasin in Indonesia. This study was conducted during the dry season in June 2015, and the geographic coordinates of this site are given by 03° 25' 19.6" S and 114° 45' 55" E with an elevation of 50 m a.s.l (as shown in Figure 1).

Figure 1. Location of the study area: Tegal Arum Village in South Kalimantan, Indonesia.

2.1 Soil Samples

Soil samples were taken from the field using a 4 cm diameter hand auger. Then, the soils were dug down vertically to 3 m in depth using the hand auger in 0.5 m intervals. The hand auger must be cleaned before and after using it so that the samples of soils are not contaminated by another sample. Then, samples were wrapped with aluminum foil before being stored in PVC pipes so that the moisture remains. In the laboratory, σ measurements of the samples were conducted per 1 cm using the EM 50 data logger. For χ_m measurements, samples were sliced 1 cm thick and placed in cylindrical plastic holders (2.5 cm in diameter, 2.2 cm in height). The mass of each sample was measured using an OHAUS analytical balance. After that, each sample was measured for mass and then measured for its χ_m using the Bartington MS2 magnetic susceptibility system (Bartington Instruments Ltd., England) with an MS2B sensor set to a frequency of 470 Hz. The soil samples were analyzed in a chemical laboratory, TekMIRA (Research and Development Center of Mineral and Coal Technology) using loss on ignition LOI measurement with an ASTM-D2974 standard. For the measurement of LOI, the first step was to heat an empty cup then put it into the furnace at 800–900 °C for 30 minutes. Then the cup was inserted into the desiccator for 15 minutes and weighed (weight A). After that, the soil sample (1 g) was put into a cup and weighed (weight B). Next, the cup with the soil sample was inserted into the furnace at 800–900 °C. After that, the sample was inserted into the desiccator and re-weighed as weight C. The LOI content was calculated using the formula

$$\%LOI = \frac{B-C}{B-A} \times 100\% \quad (1)$$

Note the sample soil had been dried for 1 hour at 100–110 °C.

2.2 K-Means Cluster Method

The cluster method is used in the separation of random data into several clusters based on heterogeneous data. One group must have homogeneous data. There are several types of cluster methods. The K-means method is effective in clustering more than 100 data. The K-means cluster chooses the number of clusters K randomly and more K cluster center locations. The distance of each data point to the central data was calculated by finding the smallest distance between each point to each centroid. The new centroid is calculated by finding the smallest distance between input vectors and the centroid vector, and this is repeated until iteration to convergence. The iterate determined the criteria for updating new cluster centers. In maximum iterations, it determined the maximum number of the iterations. Convergence criterion was used to decide when to close the iteration process.

3. Results and Discussions

3.1 Magnetic Susceptibility (χ_m) and Electrical Conductivity (σ) Properties

The measured χ_m properties range from -2.4 to $68 \times 10^{-8} \text{ m}^3/\text{kg}$, as shown in Figure 2a. The soil from 0–5 cm depth has the maximum χ_m properties. There were minimum and negative χ_m properties at 6 to 147 cm depth, and soil below 147 cm had positive χ_m properties. The σ properties differ from the χ_m properties. Up to 185 cm in depth, there is an increase of the σ properties. The σ properties were lower at 185–237 cm depth. Below 237 cm depth there is an increase of the σ properties. The boundary layers could not be determined based on the measurement of the properties, so the boundary layers can be determined using cluster method. There were 272 data points for the χ_m and the σ properties because more than 100 data points are needed to use the K-means cluster method effectively.

3.2 K-Means Cluster Analysis

The data of the χ_m and the σ properties have large ranges of value (as shown in Figure 2a). To improve the efficiency of the process, the K-means cluster used SPSS analysis and, for this, the data must be normalized. This is shown in Figure 2b. In K-means clustering, the researcher designates the number of clusters. We used two clusters. This means two layers. The first step chose the first centroid for each of the χ_m and the σ properties in minimum and maximum values (shown in Table 1). Table 1 showed that there were two clusters for the χ_m properties with the minimum values in cluster 1 and maximum values in cluster 2. For the σ properties, the maximum values were in cluster 1 and the minimum in cluster 2.

Figure 2. (a) Magnetic susceptibility (χ_m) and electrical conductivity (σ) data. (b) Magnetic susceptibility (χ_m) and electrical conductivity (σ) normalized data.

Table 1. Maximum and minimum centroid.

Initial Cluster Centers		
	Cluster	Cluster
	1	2
χ_m Norm	.045	1.000
σ Norm	1.000	.308

In the second step, the results of the minimum and maximum values from first centroid are re-calculated with each iteration to find new centroid. This analysis determined 15 iterations (as shown in Table 2). The iteration is re-updated automatically when the centroid finds the right centroid for each cluster. The number cluster is determined to be accurate if 15 iterations have the convergent centroid obtaining 0 (zero). Determination of the number cluster is done to analyze the data [30]. The iteration is in 15 iterations; however, the convergent criteria obtains 0–13 iterations. Therefore using two clusters for this data has been appropriated.

Table 2. History of iteration centroid cluster.

Change in Cluster Centers		
Iteration	1	2
1	.733	.839
2	.005	.043
3	2.293E-5	.001
4	9.596E-8	3.550E-5
5	4.015E-10	1.014E-6
6	1.680E-12	2.898E-8
7	6.895E-15	8.279E-10

8	.000	2.365E-11
9	.000	6.761E-13
10	.000	1.913E-14
11	.000	5.796E-16
12	.000	1.110E-16
13	.000	.000

Results of the K-means cluster iteration showed that the final centroid for each cluster (see Table 3). The number cluster is shown in detail in Appendix A. It can be seen that the data above 248 cm in depth is in cluster 1, except for 1 and 2 cm data which was included into cluster 2. Cluster 2 is comprised of the data below 248 cm. The results of clustering are two layers of sample soil with the boundary layer at 248 cm (as shown in Figure 3). Layer 1 is above 248 cm and has the lowest and negative χ_m and σ properties. Layer 2 is below 248 cm and has higher and positive χ_m and σ properties.

Table 3. Final centroid in cluster.

Final Cluster Centers		
	Cluster	
	1	2
χ_m Norm	.007	.177
σ Norm	.216	.781

The χ_m property changes of soil are affected by how much magnetic mineral are in the soil samples. The soils with higher organic matter content or lower magnetic mineral have lower χ_m properties [17–19]. Layer 1 with lower χ_m properties is associated with peat soil because lower χ_m properties tend to show diamagnetic properties, such as in peat [31]. The σ properties of peat soil are lower than mineral soil [32] or the resistivity of peat soil is higher than mineral soil [1]. Resistivity properties can be applied in the analysis of the organic content of soil because the σ properties are contrary to resistivity [33]. Layer 2, shown in Figure 3b, has the higher χ_m and σ properties associated with mineral soil.

Measuring the LOI content is a direct method to determine the organic content of soil [34–36]. The LOI measurement is a simple and a cheap method to determine organic content [37]. The soil sample has more than 75% organic content, and it is associated with peat soil [38]. Wüst et al. [39] categorized the soil sample in Tasek Bera Basin, Malaysia with LOI content of >45%, which is associated with peat soil. In any case, tropical peat has a higher LOI content and C-organic content [3]. Lupachev et al. [40] showed that the soil in Turbic Cryosol in Russia with humus and organic soil has 8–35% LOI content, which is associated with mineral soil. The results of this study showed that there are two layers: layer 1 with 86.80% LOI content and layer 2 with 26.11% LOI content. According to the results, layer 1 was associated with peat soil and layer 2 with mineral soil. Distribution of the σ and the χ_m properties against depth was shown in Figure 3a, and the layering with the peat layer (represented by a triangle mark) and the mineral layer (represented by a circle mark) is shown in Figure 3b.

Figure 3. (a) Magnetic susceptibility and electrical conductivity before clustering. (b) Magnetic susceptibility (χ_m) and electrical conductivity (σ) with clustering (layer 1 represented by a triangle and layer 2 represented by a circle).

4. Conclusions

K-means clustering is more effective for a larger number of data, but the data must be normalized. The K-means cluster is efficient in delineate layering of a soil sample. The soil sample is divided into two layers, namely a peat soil layer and a mineral soil layer. The magnetic susceptibility and electrical conductivity properties of peat soil are lower than mineral soil, and they are appropriated with organic content as shown using the LOI test.

Acknowledgments: The authors would like to thank Tegal Arum village officials in the South Kalimantan, Indonesia for their cooperation and support during the field measurement and The Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the research grant.

Author Contributions: Mimin Iryanti, Satria Bijaksana, Wahyu Srigutomo, and Tedy Setiawan conceived the idea for this study. Mimin Iryanti, Ahmad Aminudin, and Eleonora Agustine prepared the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Cluster membership of case numbers

Case Number	Depth (m)	Cluster	Distance	Case Number	Depth (m)	Cluster	Distance	Case Number	Depth (m)	Cluster	Distance	Case Number	Depth (m)	Cluster
1	1.00	2	.711	69	73.00	1	.226	137	142.00	1	.150	205	217.00	1
2	2.00	2	.874	70	74.00	1	.149	138	143.00	1	.187	206	218.00	1
3	4.00	1	.560	71	75.00	1	.187	139	144.00	1	.112	207	219.00	1
4	5.00	1	.172	72	76.00	1	.112	140	145.00	1	.112	208	220.00	1
5	6.00	1	.122	73	77.00	1	.075	141	146.00	1	.111	209	221.00	1
6	7.00	1	.161	74	78.00	1	.075	142	147.00	1	.153	210	222.00	1
7	8.00	1	.046	75	79.00	1	.039	143	148.00	1	.153	211	223.00	1
8	9.00	1	.024	76	80.00	1	.076	144	149.00	1	.072	212	224.00	1
9	10.00	1	.021	77	81.00	1	.075	145	151.00	1	.034	213	225.00	1
10	11.00	1	.040	78	82.00	1	.073	146	152.00	1	.073	214	226.00	1
11	12.00	1	.039	79	83.00	1	.074	147	153.00	1	.084	215	227.00	1
12	13.00	1	.023	80	84.00	1	.075	148	154.00	1	.084	216	228.00	1
13	14.00	1	.030	81	85.00	1	.111	149	155.00	1	.084	217	229.00	1
14	15.00	1	.049	82	86.00	1	.187	150	156.00	1	.046	218	230.00	1
15	16.00	1	.051	83	87.00	1	.150	151	157.00	1	.007	219	231.00	1
16	17.00	1	.043	84	88.00	1	.149	152	158.00	1	.046	220	232.00	1
17	18.00	1	.028	85	89.00	1	.075	153	159.00	1	.007	221	233.00	1
18	19.00	1	.040	86	90.00	1	.111	154	160.00	1	.046	222	234.00	1
19	20.00	1	.045	87	91.00	1	.110	155	161.00	1	.047	223	235.00	1
20	21.00	1	.044	88	92.00	1	.111	156	162.00	1	.026	224	236.00	1

Case Number	Depth (m)	Cluster	Distance
21	22.00	1	.028
22	23.00	1	.026
23	24.00	1	.041
24	25.00	1	.041
25	26.00	1	.042
26	27.00	1	.187
27	28.00	1	.150
28	29.00	1	.150
29	30.00	1	.227
30	31.00	1	.226
31	32.00	1	.111
32	33.00	1	.075
33	34.00	1	.042
34	35.00	1	.032
35	36.00	1	.147
36	37.00	1	.048
37	38.00	1	.075
38	39.00	1	.036
39	40.00	1	.040
40	41.00	1	.044
41	42.00	1	.026
42	43.00	1	.023
43	44.00	1	.037
44	45.00	1	.075

Case Number	Depth (m)	Cluster	Distance
89	93.00	1	.112
90	94.00	1	.074
91	95.00	1	.074
92	96.00	1	.075
93	97.00	1	.077
94	98.00	1	.074
95	99.00	1	.074
96	101.00	1	.271
97	102.00	1	.041
98	103.00	1	.075
99	104.00	1	.075
100	105.00	1	.031
101	106.00	1	.187
102	107.00	1	.226
103	108.00	1	.041
104	109.00	1	.043
105	110.00	1	.074
106	111.00	1	.076
107	112.00	1	.150
108	113.00	1	.112
109	114.00	1	.187
110	115.00	1	.075
111	116.00	1	.111
112	117.00	1	.075

Case Number	Depth (m)	Cluster	Distance
157	163.00	1	.023
158	164.00	1	.016
159	165.00	1	.046
160	166.00	1	.047
161	167.00	1	.024
162	168.00	1	.046
163	169.00	1	.056
164	170.00	1	.047
165	171.00	1	.046
166	172.00	1	.009
167	173.00	1	.019
168	174.00	1	.007
169	175.00	1	.052
170	176.00	1	.084
171	177.00	1	.046
172	178.00	1	.014
173	179.00	1	.138
174	180.00	1	.200
175	181.00	1	.200
176	182.00	1	.161
177	183.00	1	.202
178	184.00	2	.264
179	185.00	2	.267
180	186.00	2	.237

Case Number	Depth (m)	Cluster
225	237.00	1
226	238.00	1
227	239.00	1
228	240.00	1
229	251.00	2
230	252.00	2
231	253.00	2
232	254.00	2
233	255.00	2
234	256.00	2
235	257.00	2
236	258.00	2
237	259.00	2
238	260.00	2
239	261.00	2
240	262.00	2
241	263.00	2
242	264.00	2
243	265.00	2
244	266.00	2
245	267.00	2
246	268.00	2
247	269.00	2
248	270.00	2

Case Number	Depth (m)	Cluster	Distance
45	46.00	1	.187
46	47.00	1	.109
47	48.00	1	.148
48	52.00	1	.071
49	53.00	1	.071
50	54.00	1	.032
51	55.00	1	.070
52	56.00	1	.148
53	57.00	1	.072
54	58.00	1	.112
55	59.00	1	.111
56	60.00	1	.149
57	61.00	1	.112
58	62.00	1	.150
59	63.00	1	.112
60	64.00	1	.112
61	65.00	1	.113
62	66.00	1	.112
63	67.00	1	.150
64	68.00	1	.149
65	69.00	1	.225
66	70.00	1	.149
67	71.00	1	.072
68	72.00	1	.110

Case Number	Depth (m)	Cluster	Distance
113	118.00	1	.150
114	119.00	1	.111
115	120.00	1	.149
116	121.00	1	.041
117	122.00	1	.071
118	123.00	1	.110
119	124.00	1	.077
120	125.00	1	.077
121	126.00	1	.117
122	127.00	1	.078
123	128.00	1	.229
124	129.00	1	.226
125	130.00	1	.112
126	131.00	1	.077
127	132.00	1	.086
128	133.00	1	.076
129	134.00	1	.076
130	135.00	1	.074
131	136.00	1	.079
132	137.00	1	.074
133	138.00	1	.075
134	139.00	1	.075
135	140.00	1	.149
136	141.00	1	.111

Case Number	Depth (m)	Cluster	Distance
181	187.00	2	.262
182	188.00	1	.164
183	189.00	1	.164
184	190.00	1	.239
185	191.00	2	.257
186	192.00	1	.276
187	193.00	1	.148
188	194.00	1	.056
189	195.00	1	.077
190	196.00	1	.110
191	197.00	1	.111
192	201.00	1	.040
193	202.00	1	.052
194	203.00	1	.037
195	205.00	1	.125
196	208.00	1	.161
197	209.00	1	.124
198	210.00	1	.037
199	211.00	1	.110
200	212.00	1	.148
201	213.00	1	.225
202	214.00	1	.148
203	215.00	1	.186
204	216.00	1	.186

Case Number	Depth (m)	Cluster
249	271.00	2
250	272.00	2
251	273.00	2
252	274.00	2
253	275.00	2
254	276.00	2
255	277.00	2
256	278.00	2
257	279.00	2
258	280.00	2
259	281.00	2
260	282.00	2
261	283.00	2
262	285.00	2
263	286.00	2
264	287.00	2
265	288.00	2
266	289.00	2
267	290.00	2
268	291.00	2
269	292.00	2
270	293.00	2
271	294.00	2
272	295.00	2

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