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Assessment of peat fire susceptibility for carbon emission reduction

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Abstract. This paper aims are; a) to identify the peat classification based on peat depth and groundwater level; b) to identify CO_2 content stored and CO_2 emission of peat within the study area; c) to produce a hotspot hazard map using Analytical Hierarchy Process (AHP) and geospatial technologies. These are vital components in producing a holistic peat fire management approach. Based on the site works, the majority of the peat within the area is classified as Sapric (low fibre content) using the Von Post Classification System, with an average peat thickness of 0.65m at a maximum depth of 1.2m and average groundwater level of 0.67m. On the other hand, soil samples were collected on-site and tested, indicating an average organic and fibre contents of 45.24% and 37% respectively, with a bulk density of 1.03 Mg/m^3. The average carbon content was 30.29 carbon tonne/hectare, hence having the potential to release 381,925.18 tonnes of CO_2 annually (tCO_2/year). Finally, potential peat fire susceptible areas were classified and visualized on a hotspot hazard map utilizing the data acquired. It can be concluded that continued development without considering appropriate mitigation measures will potentially increase the feasibility of peat ignition, thus, increasing overall carbon emission significantly.

Keywords: Tropical peatlands, climate change, fire susceptibility, organic content, carbon emission

1. Introduction

Peat fire risk management is an extremely pertinent issue in the context of the abatement of carbon emissions, more specifically within the frame of reference pertaining to global climate change [1]. This is because peatlands perform a critical role in regards to the accumulation of carbon (increasing up to 25% of carbon in the terrestrial biosphere), consequently their deterioration releases such a considerable amount of carbon that it wields an impact on the global climate [2]. Moreover, fire has the ability to agitate the carbon stored in peats which accounts for almost the total amount of carbon in the atmosphere [3]. Despite the fact of undisturbed peat being naturally fire resistant in the tropics due to their immense moisture retention, it has been expressed that human activity such as plantation development, logging, and agriculture have led to tropical peatlands being more susceptible to burning [4]. Therefore, the aim of this study is to assess the fire susceptibility of Kampung Sungai Jarom located in Telok Panglima Garang, Daerah Kuala Langat, Selangor (Figure 1). Three main vital components are (i) identify the peat classification in relation to peat depth and groundwater level; b) identify CO_2 content stored and CO_2 emission of peat within the study area, and c) analysis of hotspot hazard map using Analytical

Hierarchy Process (AHP) and geospatial technologies. These necessary and relevant data which in turn may assist in the adoption of the necessary mitigation measures and the production of a holistic peat fire management approach.

Figure 1. Location of the study area

2. Materials & Methods

2.1. Groundwater level, peat collection and characterization procedures

The overall research methods included in this study have been categorized into three parts that state the first impression of how the research is going to be done. Initially, the groundwater level was identified by conducting site work mainly consisting of piezometers, resistivity survey and borehole exploration [5]. The Von Post classification system was used to classify peat samples collected. The von Post humification test (von Post classification system) involves squeezing the peat and the material that is extruded between the fingers, examining the material, and classifying the soil as belonging to one of ten (H1–H10) humification or decomposition categories. Peats are then further subdivided into fibric or fibrous peats (humification range of H1–H3), hemic or moderately decomposed peats (H4–H6), or sapric or amorphous peats (H7–H10). The classification of organic soil or peat for engineering purposes mainly involves using the ignition test (ASTM D 2974) to determine the organic content or determining the percentage of organic content lost on ignition [6].

The soil samples were collected using peat auger and tested in the laboratory to determine its bulk density (BD), organic carbon content and ash content.

2.1.1. Bulk Density. Bulk density (BD) of the peat was determined in the laboratory by a gravimetric method. Samples was taken using a peat auger soil core or hollow metal box, each with associated sample volume. The calculation required to determine BD is as shown in (Eq. 1):

$$BD = M_s/V_t = [(M_s + M_c) - M_c]/V_t \qquad \text{Eq. (1)}$$

2.1.2. Soil organic carbon content. Determination of soil organic matter content was done using the LOI method. The mass of soil solids, Ms, consists of the mass of organic matter, Mom, and the mass of ash, Mash. In the LOI method, all organic matter present in the soil sample is burned at a temperature of 550 ºC for 6 hours. The burned organic matter will evaporate, and the remaining material is inorganic matter such as clay, silt, and other non-combustible substances that are collectively called ash for the purpose of this analysis. The mass lost from the sample equals the mass loss of organic matter.

Conversion of organic matter to organic carbon content uses the conversion factor of 1/1.724. This method is semi-quantitative since the mass lost during the conversion reflects only the organic matter content and the conversion factor of 1/1.724 is a generalized relationship between organic matter and carbon content.

Organic carbon content, C_{org}, is calculated based on dry weight (g of Carbon/g of dry soil) (Eq. 2):

$$C_{org} = \frac{M_s - M_{ash}}{M_s} / 1.724 = \left\{1 - \frac{M_{ash}}{M_s}\right\} / 1.724 \quad \text{Eq. (2)}$$

2.1.3. Soil organic carbon content. The ash content can be calculated as below (Eq. 3):

$$Ash\ content\ (\%) = M_{ash}/M_s\ 100\% = 100\% - C_{org}\% \quad \text{Eq. (3)}$$

C_{org} content is usually expressed in % by weight or weight fraction of organic matter to total dry weight. Organic matter content by soil volume, Cv, can be calculated as (Eq. 4):

$$C_v = BD \times C_{org} \quad \text{Eq. (4)}$$

C_v is the weight of organic carbon per unit volume of soil and ca be expressed in g/cm^3 or kg/dm^3 or tonnes/m^3.

2.2. Carbon stocks in a landscape or peat dome calculation

Carbon stocks in a landscape of peat soil can be calculated by using the data of area of each class of peat depth (A_i), the average thickness of the peat in each thickness class (h_i) and the average data for BD. and C_{org} for each peat layer and peat area [7]. The equation is as below (Eq. 5):

$$C_{stock} = \sum\left(A_i \times h_i \times BD \times C_{org}\right) = \sum(A_i \times h_i \times BD \times C_v) \quad \text{Eq. (5)}$$

2.3. Map production

Lastly, in order to identify and map potential areas for peat ignition, geospatial technology was used which includes Remote sensing, Geographic Information System (GIS), and field data collection. Then all data were analyzed using the mathematical model of Analytical Hierarchy Process (AHP), A flowchart of the method used to produce a hotspot hazard map is shown in Figure 2.

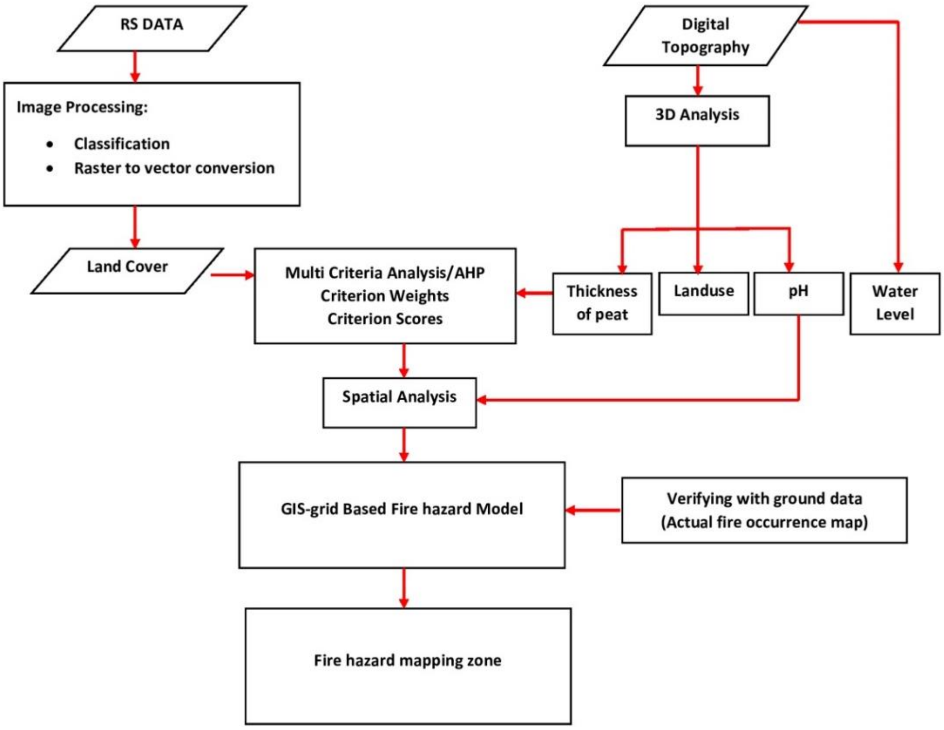

Figure 2. Flowchart for the production of fire hazard map

2.4. Mathematical model

Lastly, in order to identify and The Analytical Hierarchy Process (AHP) is a method used to generate the weightage value after each criterion is assessed to identify the possibility of a forest fire. The most consistent evaluation (lowest degree) will be utilised as a potential factor of forest fire within a region. Once the weightage values have been determined via AHP, the GIS technique can be used to analyse the output or result spatially. To get the final output, all included raster data are merged after each raster data is multiplied by the weightage value determined using the AHP approach [8]. The AHP method's final output is based on the aims or objectives to be reached. The formation of the AHP structure begins with the objectives to be reached, the criteria, and sub-criteria [9].

3. Results & Discussions

3.1. Peat collection and groundwater level

Based on the site work, majority of the peat within the area is classified as Sapric (H8) which has low fibre content according to its degree of humification as described in the Von Post system [10], with an average peat thickness of 0.65 m and a maximum depth of 1.20m. In addition, laboratory results showed that the organic and fibre contents was found to be at 45.24% and 37.00% respectively. Bulk density was also determined to be at 1.03Mg/m^3. Table 1 shows a summary of the results of laboratory tests on soil samples collected.

Groundwater level within the study area was also measured as recorded in Table 2. The study has also revealed that the peat soil within the area have a high-water table, at a depth of 0.5m to 0.8m from the surface level. However, these areas are very vulnerable and have the potential to experience peatland fires if the ground water level suffers a continuous decline due to drought or uncontrolled surrounding development that drains the area without considering the sensitivity of the impacts towards the adjacent peatland.

Table 1. Summary of laboratory tests for soil samples collected

Parameter	Values
Moisture content (%)	304.00
Bulk density (M(Mg/m^3)	1.03
Dry density (Mg/m^3)	0.20
Specific gravity, SG	1.83
Compression index	8
Organic content (%)	45.24
Fibre content (%)	37.00
pH	3.56
Von post scale	H8 (SAPRIC)

Table 2. Groundwater level within study area

Borehole no.(HA)	Groundwater level (m)
1	0.50
2	0.60
3	0.80
4	0.60
5	0.55
6	0.80
7	0.55
8	0.70

Apart from that, the results of the study also found a number of peatland areas that have experienced a decrease in the ground water level lower than the thickness of the peat soil itself due to the existing drainage system without control. Among the locations identified are as shown in Table 3. The peat soil depth for these locations is between 0.15 m and 0.72 m with the water level depth between 0.50 m and 0.80 m. Therefore, it was found that an estimated thickness of 0.08 m up to 0.55 m are exposedto the process of weathering and immediate drying. These areas are classified as being at high risk of experiencing fire, which are called hotspot areas.

Table 3. Water table depth lower than the peat soil level

Borehole No. (HA)	Water level (m)	Peat soil level (m)	Thickness of peat soil layer that is at risk of fire (m)
1	0.50	0.30	0.20
3	0.80	0.72	0.08
6	0.80	0.55	0.25
7	0.55	0.40	0.15
8	0.70	0.15	0.55

3.2 CO_2 Content Stored and CO_2 Emission of Peat

Based on the data from Table 4, total carbon content and potential total annual CO_2 emissions were calculated using Eq. (6) and Eq. (7), respectively [11].

$$Carbon\ content = A \times B \times C \times D \qquad \text{Eq. (6)}$$

where, A is peat soil area (m^2), B is average depth of peat soil in the area (m), C is bulk density (Mg/m^3) and D is organic content of peat (%, wt./wt.).

$$Annual\ CO_2 emission, E = (E_a + E_{bb} + E_{bo})/Time \qquad \text{Eq. (7)}$$

E_a is CO_2 emission from above ground biomass decomposition, E_{bb} is CO_2 emission from peat fire occurrence, E_{bo} is CO_2 emission from peat decomposition, and Sa is CO_2 uptake by vegetation [12].

Based on the calculation, the estimated total carbon content was 30.290 tonne/hectare and potential total annual CO_2 emissions was found to be at 381.925 tonnes CO_2/ year of the study area of 6.81km^2 or 681 hectare.

Table 4. Parameters used to determine carbon content and annual CO_2 emissions

Parameters	Values
Area (hectare), A	681.000
Average Thickness of Peat Soil(m), B	0.650
Bulk density (Mg/m^3), C	1.030
Organic Content (%), D	45.240
Carbon Content (tons of carbon)	20.626
Carbon Content (tonnes/hectare)	30.290
Emissions of CO2 (CO2/year)	381,925.180

3.3 Fire hazard map

The most crucial element of a peat fire hazard area map is the spatial distribution of peat forest fire occurrence. Based on information from previous research, this is mainly controlled by the thickness of peat, water level, pH value, and land use (Table 5(a)). Classification from the highest to the lowest potential of forest fire occurrence is imperative. Classification is done based on the lowest to the highest value in the summation of each raster data that represents the criteria and sub-criteria involved (Table 5(b)). Based on the calculated weightage using the four represented criteria, a hazard map was able to be produced visualizing the different classes indicating potential of peat fire occurrence [13]. The hotspots which have the highest risk of peat fire ignition, were identified to be located in the centre and towards North-East of the study area (Figure 4).

4. Conclusions

Peat fire risk management is vital for carbon emission reduction, particularly in the context of global climate change. Fire has the potential to disturb the carbon stored in peats, which globally accounts for nearly the total amount of carbon in the atmosphere. The peat within the study area was determined to be of Sapric in nature thus being more susceptible to fire due to its lower moisture content. Based on the calculations done, it was also indicated that the total estimation of carbon stock stored in the peatlands within the area is 30.29 carbon tonne per hectare, which potentially could release up to 381,925.18

tCO_2/year in the event of a peat fire occurrence. Based on the produced peat fire hazard map using Analytical Hierarchy Process (AHP), the hotspots within the study area were identified.

Table 5 (a). Factors contributing to peat fire

	Thickness (A)	Water level (B)	pH value (C)	Land use (D)
Thickness (A)		B1	A1	0.5
Water level(B)			B1	B1
pH value (C)				C1
Land use (D)				

Table 5 (b). Weightage of the criteria using Analytical Hierarchy Process (AHP)

Factor	Parameter	Bil (x)	Amount (y)	Grand amount (xy)	Weightage (xy/z)	
	0.5	1	0.5			
Thickness (A)	1	1	1	1.5	0.3	2
	2	0	0			
	0.5	0	0			
Water Level (B)	1	2	2	2	0.4	1
	2	0	0			
	0.5	0	0			
pH Value (C)	1	1	1	1	0.2	3
	2	0	0			
	0.5	1	0.5			
Land-use (D)	1	0	0	0.5	0.1	4
	2	0	0			
				5	1	

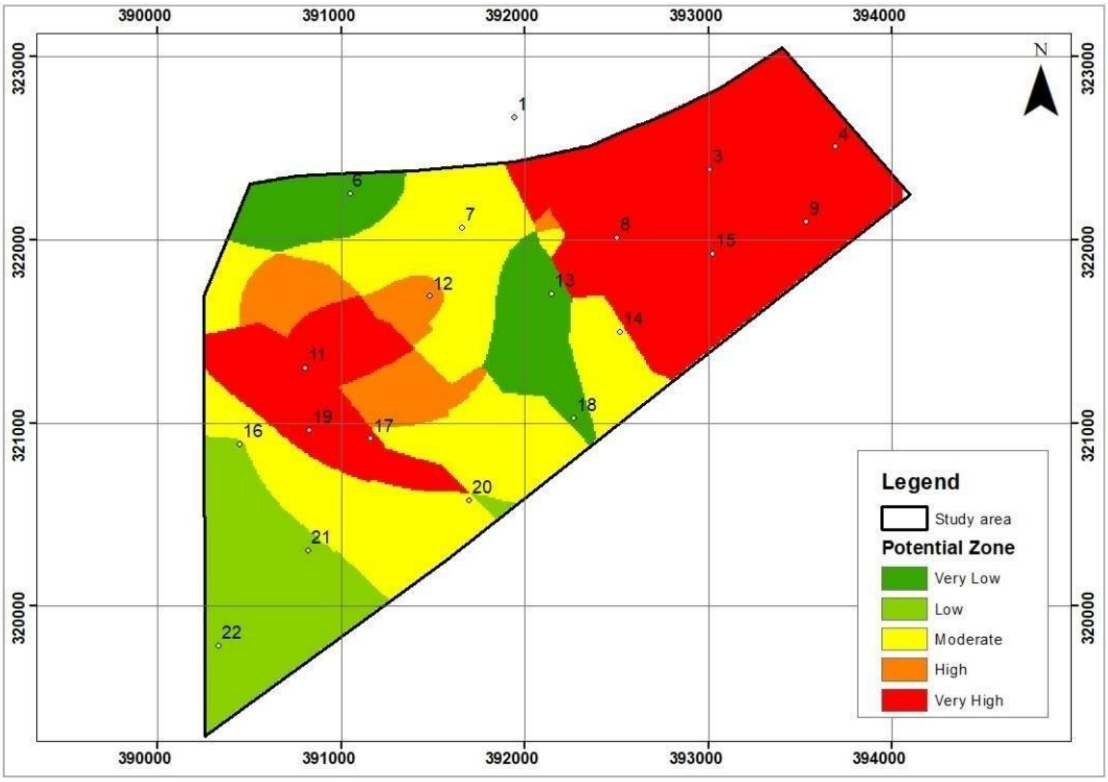

Figure 3. Peat fire hazard map

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