The potential of peatland fires estimated from physical properties for several land uses

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Abstract. The construction of drainage channels following the opening of peat ecosystems without proper water management results in rapid decline of water level in peat swamp ecosystems, which potentially causes fires. Peat land fires triggered by intentional or unintentional human negligence and are supported by long dry season. This research aims to examine the potential of peat land fires based on the physical characteristics of peat on the type of use of secondary forest land, shrub land, and oil palm land. The study was conducted on peat ecosystems for one year using survey methods and field observations. The results of study indicate that changes in peat land use from secondary forests to shrubs and oil palm plantations result in changes in some physical characteristics of peat, namely humification level, bulk density, peat thickness, organic matter content, hydraulic conductivity, and soil water content. The depth of the ground water table affects the ground water content. Potential fires occur on oil palm land and on shrub land from July to September, whereas secondary forest land does not have the potential to cause fire. In order to avoid fires in oil palm and shrub land areas, it is necessary to manage water by maintaining the groundwater level above 50 cm.

1. Introduction
Peatlands are vulnerable ecosystems, mostly prone to land fires. Peatland fires occur annually, especially during the dry season, causing social, economic, environmental, and ecological problems. Three main causes of land fires include humans, land conditions, and climate [1,2]. Meanwhile, according to Imanudin et al. [3], peatland fires are closely related to unutilized and left open lands. Peatland fires occur when triggering and supporting factors are existed. The trigger of fires involves human negligence related to land preparation, fishing, and hunting. Meanwhile, the supporting factors include the construction of uncontrolled drainage channels, land cover changes, and a long dry season. The construction of drainage channels that does not follow water management results in a rapid decrease in the water level on peatlands. The clearing of peatlands results in reduced vegetative cover causing the soil surface to dry quickly. This decrease in water level is not only due to the absence of water sources in the dry season, but also due to the high porosity of peat and the low capillarity of water in peat soils.

Land conversion from forest peatlands to agricultural land has been widely reported causing a decrease in the groundwater table. Szajdak and Szatylowicz [4] revealed that the long-term exploitation of peatland for agriculture and other forms of exploitation causes a number of impacts including a decrease in ground water table, increased aeration, carbon release, and subsidence.
Consequently, peat soil will experience drought and cause irreversible drying or hydrophobicity [5,6]. This will result in land fires. Several studies have reported that peatland fires occur in various land holding schemes, including small holder plantations, plantations owned by the government and also privately owned, as well as shrubs left by land owners. This study will investigate the potential for land fires that will occur in three different land uses, namely secondary forest, shrubs, and oil palm plantation.

2. Materials and methods
2.1. Study sites
This study was conducted at peatland of tropical rain forest located in Pedamaran Timur Sub-District, Ogan Komering Ilir District, South Sumatera Province, Indonesia (Figure 1). Field sampling was determined purposively on three land uses, i.e. secondary forest, shrubs and oil palm plantation.

![Figure 1. Study site.](image)

2.2. Measurement and sampling
Tools and materials included maps (administration, soil, topography, and land use), Global Position System, auto level, peat driller, mineral driller, ring samples, soil conductivity gauge, and tools for measuring ground water tables. The research work was divided into field and laboratory works.

The field works involved measurement and peat sampling. Peat depth was measured by using peat driller, hydraulic conductivity was gauged by using auger holes, water level was gaged by using measuring tape, while humification level was measured by using van Post method. Five-peat samples were collected randomly from study sites with the plot size of 250,000 m². The sampling points were made perpendicular to the river. Undisturbed cores were collected by using a metal cylinder for analysis of bulk density. Bulk samples were collected by using peat auger for analysis of organic matter content and soil moisture content.

2.3. Soil analysis
Soil analysis was conducted at the Soil Science Laboratory of Jambi University. Undisturbed cores were determined for bulk density, while bulk samples were determined for organic matter content and peat water content. Bulk density was derived from dividing oven-dried mass by known volumes. Moisture content was assessed by oven drying the sample at 105 °C for 48 hours. Organic matter contents were quantified using the loss on ignition methods [7].
3. Results and discussion
Conversion of peat forest into other land uses resulted in reducing vegetative cover which impacted to changes of several properties of peat as shown in Table 1. The conversion of forest land into shrubs and oil palm caused a decrease in organic matter, peat thickness, hydraulic conductivity, and water content. On the other hand, there was an increase in bulk density and maturing peat.

### Table 1. Change in soil physical properties of peat due to land conversion.

| Variables                          | Secondary forest | Shrubs     | Oil palm plantation |
|------------------------------------|------------------|------------|---------------------|
| Groundwater table (cm)             | 40 – 50          | 50 - 60    | 60-70               |
| Organic matter content (%)         | 96.73 ± 2.44     | 92.75 ± 1.79 | 89.61 ± 1.08       |
| Humification level                 | Hemic            | Hemic      | Hemic – Sapric      |
| Peat depth (cm)                    | 850 ± 125        | 755 ± 133  | 550 ± 107           |
| Bulk density (g cm⁻³)              | 0.11 ± 0.02      | 0.14 ± 0.03 | 0.16 ± 0.04        |
| Hydraulic conductivity (cm hour⁻¹) | 43.20 ± 2.46     | 19.63 ± 2.17 | 12.42 ± 2.89     |
| Moisture content (%)               | 650 ± 34         | 520 ± 37   | 430 ± 27            |

There were changes in the level of humification of peat on the surface of oil palm plantation from hemic to sapric (previously forest and shrub land) due to decreasing groundwater table. This decrease affected the decomposition of organic matter which results in changes in humification process [8]. Groundwater table is the main factor affecting peat humification [9]. The changes of peat humification are generally accompanied by a decrease in peat depth.

The decrease of organic matter was observed from secondary forest to shrub land and oil palm plantation. Altering secondary forest to oil palm plantation was initiated by making drainage channels, felling trees, and tilling the soil using heavy equipment. More drainage channels and more densely spaced on and under bush land thicken the aeration zone that activates aerobic microorganisms. Consequently, the decomposition of organic matter increases [10]. In addition, felling trees in secondary forests and replacing natural vegetation with monocultures of oil palm and shrubs reduced the biomass and organic matter [11]. Lower organic matter of oil palm plantation compared to of shrubs was due to exposing soil surface at the beginning of oil palm planting, tillage, and fertilization, which results in faster decomposition of organic matter.

Organic matter affects bulk density, hydraulic conductivity, and moisture content. There was a negative relationship between soil organic matter and soil bulk density where a decrease in organic matter will increase bulk density. On the other hand, there was a positive relationship between organic matter, hydraulic conductivity and water content. The decrease in organic matter led to decreasing hydraulic conductivity and water content.

The three land uses showed bulk density in the same range of 0.1-0.2 g cm⁻³ which was similar to the result of previous researchers [12–14]. This shows that secondary forest, shrubs, and oil palm plantation have not yet fully decomposed, at the peat humification of hemic, except for the surface layer of oil palm plantation. However, there were differences of bulk density in the three fields, where the highest bulk density was found in oil palm land followed by shrubs and secondary forest.

This was due to the compaction of peat following the decomposition of coarser materials into finer ones. The compaction accelerated the decreasing water flows [15]. Peat compaction, decreasing organic matter content, and increasing the humification level of peat from hemic to sapric, from secondary forest to shrubs and oil palm land reduced water content by 650%, 520%, and 430% respectively.

Monthly groundwater table in secondary forest, shrubs, and oil palm land demonstrated significant differences (Figure 2). The deepest groundwater table was observed in oil palm and the shallowest was
in secondary forest. The depth of groundwater table per month seems to be influenced by the amount of rainfall. Figure 2 illustrates that the groundwater table of secondary forest was about 40 cm in August – September.

Figure 2. Water level in 3 land uses.

The depth of groundwater table affects the water content above it (Table 2). The deeper the groundwater table, the lower the water content can be.

Table 2. Water content above groundwater table.

| Layer above the water table (cm) | Soil water content (%) |
|----------------------------------|------------------------|
|                                  | Secondary Forest | Shrubs | Oil Palm Plantation |
| 0-10                             | 542              | 509    | 526                 |
| 10-20                            | 469              | 452    | 463                 |
| 20-30                            | 371              | 388    | 367                 |
| 30-40                            | 267              | 310    | 279                 |
| 40-50                            | 196              | 224    | 192                 |
| 50-60                            | ---              | 120    | 122                 |
| 60-70                            | ---              | ---    | 105                 |

Table 2 shows that water content of peat was in the range of 200% to a depth of 50 cm above the ground water table. According to Rein et al. [16], peat will be vulnerable to burning at a moisture content of less than 125%. The water content at a depth of 50 cm may up to 196% at the soil surface. This means that when the groundwater level is 50 cm, there is unlikely of burning. Fires are possible to occur at depth above 60 cm. This is in line with the previous research stated that capillary water would be able to rise from the ground water table as high as 40-50 cm [17,18]. With an increase in capillary water to 50 cm above the ground water table, the peat was sufficiently moist even though there is no additional water on the soil surface, either from rainwater or other sources. The result is
somewhat different from the result of Schindler et al. [19] and Schwarzel et al. [20] which concluded that at depths of 70 cm, capillary water is capable to reach the root zone.

Based on annual groundwater table (Figure 2) and soil moisture content (Table 2), peatland fires potentially occurred in shrubs and oil palm plantations from July to September. In fact, during the research observations, there were no fires both in shrubs and oil palm plantations since the water content had exceeded the critical limit (>125%). The non-occurrence of fires in the three land uses in the research area is presumably due to no source of fire and successful management to protect the land from fire hazards.

4. Conclusion
Land cover change of peatland, from secondary forest to shrubs and oil palm plantation have changed several physical properties of peat, successively reducing the depth of the peat layer, organic matter, hydraulic conductivity, and soil moisture. Meanwhile, the changes led to an increase of peat humification and bulk density.

Land fires in shrubs and oil palm plantations is likely to occur between July and September, however it did not occur during the research observations. The land management that protects area from fire hazard mitigates fire occurrences even though there were supporting factors such as dry season and low water levels.

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