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Post-Fire Analysis of Topogenic Peatland Characteristics in Pelalawan Regency, Riau

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Abstract

Peatland fires contribute to overall ecosystem degradation, affecting physical, chemical, and biological components, including the loss of carbon stocks, alterations in soil structure, and a decline in land quality. This study aims to analyze changes in morphological characteristics, physical and chemical properties, and vegetation cover in burned and unburned peatlands in Pelalawan Regency. The research was conducted in the peatlands of Pangkalan Kerinci District using a descriptive approach with purposive soil sampling. The results indicated that across all three peatland conditions—peat swamp land, burned peat, and unburned peat—the peat maturity level was classified as sapric, with relatively similar physical characteristics. Peat swamp land exhibited higher water content, bulk density, particle density, and porosity compared to the other two conditions, while burned land showed the lowest water content and porosity. Variations in soil color did not correspond to significant changes in soil physical properties, suggesting that peatland fires in Pelalawan Regency did not substantially affect the morphological, physical, or chemical characteristics of the soil, which remained within the same classification range. Additionally, on the peatland burned in 2019, a natural succession process was observed, with the dominant vegetation being the grass Leersia oryzoides.

Keywords: Morphological Characteristics, Peatland Fires, Soil Chemistry, Soil Physics, Vegetation Succession Peatland

1. Introduction

Peat is an organic material formed from the incomplete decomposition of plant remains under wet and humid environmental conditions with limited oxygen availability (Mirwan & Wijayanti, 2011). In Indonesia, peatlands are estimated to cover approximately 14.95 million hectares, distributed across Sumatra, Kalimantan, Papua, and a small area in Sulawesi (Masganti et al., 2014). Soil characteristics, environmental conditions, and human management and activities strongly influence peatland productivity. However, this productivity tends to decline due to the degradation of the soil's chemical, physical, and biological properties (Maftuah et al., 2014). Additionally, the dominance of homogeneous vegetation with low biodiversity further reduces the resilience of peat ecosystems (Irma et al., 2018).

On the island of Sumatra, peatland forest degradation caused by fires is most prevalent in the provinces of Riau, Jambi, and South Sumatra (Miettinen et al., 2016). Pelalawan Regency in Riau is one of the regions with extensive peatlands and is highly vulnerable to fires, particularly during the dry season. Fires in this area are generally widespread (Cattau et al., 2016) and contribute significantly to greenhouse gas emissions (Nara et al., 2017).

The most severe damage to peatlands is caused by deep drainage and uncontrolled burning. Excessively deep drainage can lower the groundwater table, leading to: (1) a shift in the ecosystem from anaerobic to aerobic conditions, which accelerates the biological oxidation or mineralization of organic matter and increases CO_2 emissions; (2) excessive drying during the dry season, resulting in irreversible desiccation that reduces the soil's capacity to retain water and nutrients; (3) compaction of peat soil; and (4) subsidence. Meanwhile, burning, as a form of accelerated oxidation, can cause: (1) loss of soil organic matter; (2) increased nutrient release due to accelerated decomposition; and (3) elevated CO_2 emissions into the atmosphere (Nusantara et al., 2012).

Peat fires generally impact ecosystem degradation, including the loss of carbon reserves, changes in soil structure, and a decrease in the quality of physical and chemical properties such as pH, ash content, porosity, bulk density, and organic matter content (Abakumov et al.,

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2018). Many news reports about forest and land fires in Riau Province occur during the dry season. Forest and land fires (Karhutla) happened in the peatlands of Karya Indah Village, Kampar Regency, Riau, burning an area of 2 ha. According to Liputan6 news (2023), forest and land fires (Karhutla) occurred in the border area between Dumai and Bengkalis, located in Tanjung Leban and Medan Kampai, where the burned peatland had a depth of approximately 4 meters. According to Detikcom news (2022), forest and land fires (Karhutla) occurred in the peatlands of the Bengkalis area in Riau, covering an area of 4 hectares. In the EoF news (2021), forest and land fires (Karhutla) occurred in peatlands, the largest burned in Bengkalis covering an area of 82 ha, Siak Regency covering an area of 45 ha, Dumai City covering an area of 40 ha, Indragiri Hilir Regency covering an area of 40 ha, Pelalawan Regency covering an area of 26 ha, Meranti Islands covering an area of 4 ha, and Indragiri Hulu and Rokan Hilir covering an area of 5 ha. According to regional news, Kompas (2020), fires can increase soil temperature, alter its structure, and reduce infiltration capacity.

Large-scale burning causes an increase in bulk density, followed by a decrease in porosity and infiltration rate, which ultimately reduces the soil's ability to retain water (Hermanto & Wawan, 2017). In contrast, Rauf (2016) found that peatland fires in the HGU PT. Dua Perkasa Lestari area, which occurred four years prior, had led to the restoration of peatland quality. Remarkably, the physical, chemical, and biological properties of the burned peatland were better than those of unburned peatland and peatland with forest vegetation.

Considering these impacts, further Research is needed to compare the characteristics of burned and unburned peatlands. Analyzing the chemical and physical properties of peatlands provides essential baseline information for developing sustainable utilization strategies and conservation efforts.

2. Material and Methods

The research was conducted over 24 months (January-December 2024) in the oil palm plantation of Menten Village, Rambutan District, Musi Banyuasin Regency, South Sumatra, representing the tidal land ecosystem typology of overflow types A and B. The coordinate points -3.0557940574044555, 104.89264070901534 are located at an altitude of 21 meters above sea level. The research method used a factorial Completely Randomized Block Design (RAKL) with the first factor being the water management system including conventional (intensive drainage), semi-intensive (controlled drainage), conservation (partial rewetting), and optimization (smart drainage), while the second factor was the age of the oil palm plants (3-5, 6-10, 11-15, 16-20, and 21-25 years). Each treatment combination was repeated four times with a plot size of 50 × 50 m, resulting in a total of 80 experimental units.

The research was conducted in the peatland area of Pangkalan Kerinci District, Pelalawan Regency, Riau at 0° 23' 2.4" South Latitude and 101° 50' 36.24" East Longitude at an altitude of 15 meters above sea level and soil analysis was conducted at the Research and Technology Laboratory, Faculty of Agriculture, University of North Sumatra from November to December 2024. The conceptual framework used in this study is presented in Figure 1.

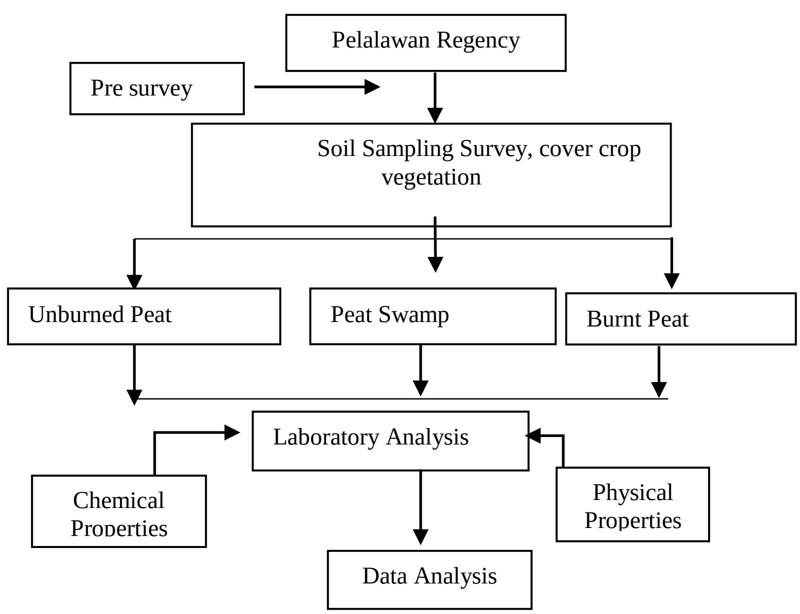

Figure 1. Research conceptual framework

The materials needed are disturbed and undisturbed peat soil samples, plastic bags, label paper and chemicals for soil chemical analysis in the laboratory. The tools used are *global positioning system* (GPS), machete, hoe, meter roll, ruler, plastic rope, stationery, documentation tools, peat drill, soil drill, brush, and equipment for soil chemical analysis in the laboratory such as pH meter, oven, *muffle furnace oven*, *shaker*, analytical balance, porcelain cup, mortar, soil sieve, plastic bottle, desiccator and other measuring tools for soil chemical analysis in the laboratory. *Purposive* soil sampling and observation were conducted on peat swamps, peatlands that had burned in 2019, and unburned peatlands. For each land condition (peat swamp, burned peat, and unburned peat), one soil sample was taken without replication.

Sampling locations were determined during the survey. Observation block areas were defined by *purposive sampling* on adjacent burned land (GT), peat swamp (RG), and unburned peat (GTT). These locations were then marked or mapped according to recorded GPS (Global Positioning System) coordinates. Soil sampling was conducted using a gauge drill to determine the bulk density. For physical and chemical analysis, the soil was sampled to a depth of 0-30 cm (disturbed soil samples), followed by sampling to depths of 30-90 cm and 90-150 cm to describe the morphological characteristics of the soil as observed in the field. A 1 kg sample of disturbed soil was taken from each observation point and placed in a clean, labelled plastic bag. Undisturbed soil samples were taken using a peat drill to observe the soil's physical properties.

The data collected were primary, namely soil morphological characteristics in the form of soil horizons, horizon depth, soil color, consistency, and horizon boundaries. The results of the analysis of peat soil chemical properties include pH and ash content. The physical properties of peat soil include: peat soil maturity, soil water content, peat soil color, bulk density, and porosity. The soil used for the analysis was disturbed and undisturbed peat soil representing post-fire and unburned land. The data obtained were analyzed both descriptively and inferentially using Microsoft Excel software, version 2016.

3. Results and Discussion

3.1. Soil Morphology

The soil morphology observed in peat swamps, burned, and unburned peatlands included peat maturity, soil color, consistency, and horizon boundaries. Morphological analysis was conducted using disturbed soil samples collected at depths of 0–30 cm, 30–90 cm, and 90–150 cm. The results of these soil morphological observations are presented in Table 1.

Table 1. Morphology of peat soil on burnt and unburnt peatlands

Location	Soil Depth	Color	Maturity
Peat Swamp	0 – 30	10 YR 2/2 Very dark brown	Hemic
	30 – 90	2.5 YR 2.5/2 Very dusky red	Hemic
	90 – 150	2.5 YR 2.5/2 Very dusky red	Fibric
Burning Peat	0 – 30	2.5 YR 3/2 Dusky red	Saprik
	30 – 90	2.5 YR 3/2 Dusky red	Saprik
	90 – 150	5R 2.5/1 Reddish black	Hemic
Unburned Peat	0 – 30	2.5 YR 2.5/2 Very dusky red	Saprik
	30 – 90	2.5 YR 2.5/2 Very dusky red	Hemic
	90 – 150	5 YR 2.5/2 Dark reddish brown	Hemic
Peat Swamp	0 – 30	Sticky	Mix
	30 – 90	A bit sticky	Mix
	90 – 150	A bit sticky	Mix
Burning Peat	0 – 30	Sticky	Mix
	30 – 90	A bit sticky	Mix
	90 – 150	A bit sticky	Mix
Unburned Peat	0 – 30	Sticky	Mix
	30 – 90	Sticky	Mix
	90 – 150	A bit sticky	Mix

Based on research results, the soil morphology in peat swamps at various depths exhibits differences in soil colour, peat maturity level, and consistency. Soil color variations are primarily influenced by organic matter content (Adji et al., 2023). At the 0–30 cm layer, the soil is very dark brown (10YR 2/2), indicating a high organic matter content and humid conditions with high water content (Suswati et al., 2011). Meanwhile, at a depth of 30–150 cm, the soil tends to be very dusky red (2.5YR 2/2) due to the accumulation of organic matter that has not yet fully decomposed. The peat maturity level at this location shows a decrease, from hemic at a depth of 0–90 cm to fibric at 90–150 cm. Saturated conditions inhibit microbial activity due to the lack of oxygen, resulting in a slow decomposition process (Haq et al., 2025). Environmental factors and time also influence the level of peat maturity. Generally, the upper layers are more mature due to faster decomposition (Sandra et al., 2022; Najiyanti et al., 2005). Soil consistency ranges from slightly sticky to sticky, while horizon boundaries are diffuse, reflecting the gradual accumulation of organic matter over time.

Burned peatlands cause changes in soil morphology due to the fire process. The soil colour in the 0–90 cm layer is predominantly dark red (dusky red, 2.5YR 3/2), with a sapric maturity level, indicating that peat has undergone advanced decomposition, making its original structure difficult to recognize. This finding is caused by high temperatures and oxidation, which accelerate the weathering of organic matter (Nurlaili, 2009). At a depth of 90–150 cm, the soil is reddish black (5R 2.5/1) with a hemic maturity level, indicating that the fire did not penetrate deeper layers. Soil consistency remains somewhat sticky to sticky, due to a reduction in light organic matter and an increase in mineral fractions. Diffuse horizon boundaries are still visible, indicating that layer transitions occur naturally despite the fire.

In contrast, unburned peatlands exhibit relatively natural morphological conditions. The soil color at a depth of 0–90 cm is generally very dusky red (2.5YR 2/2) with a high organic matter content. In deeper layers (90–150 cm), the colour changes to a dark, reddish-brown (5YR 2.5/2), indicating advanced decomposition. The peat maturity level varies, from sapric in the upper layer (0–30 cm) to hemic at a depth of 30–150 cm, reflecting a gradual decomposition process. Soil consistency also changes with depth, from sticky in the upper layer to slightly sticky in the lower layer. Diffuse horizon boundaries indicate a gradual accumulation of organic matter (Irsal et al., 2024).

3.2. Physical Properties of Soil

The results of the physical properties of the peat soil that have been analyzed were obtained from undisturbed soil samples (soil drilling) at a depth of 0-30 cm in the upper layers of burned, unburned peat soil, and peat swamp. The physical properties of the soil obtained are presented in Tables 2 and 3.

Table 2. Soil color, water content, and *bulk density* of peat soil on burnt and unburnt peatlands

Location	Earth Color	Water content (%)	*Bulk Density* (g/cm ^{3})
Peat Swamp	7.5 YR 3/2 Dark Brown	1617.46	0.13R
Burning Peat	10 YR, 2/2 Very dark brown	613.42	0.12R
Unburned Peat	2.5 YR 2.5/2 Very dusky red	1076.47	0.12R

Observations (Table 2) indicate that the soil colour at the three locations varies. In peat swamps, the soil is characterized by a dark brown colour (7.5YR 3/2), reflecting water-saturated conditions and slow decomposition (Agus et al., 2014). In burned peat, the soil colour is darker (10YR 2/2), influenced by the accumulation of charcoal from the combustion process. Meanwhile, in unburned peat, the soil color tends to be very dusky red (2.5YR 2.5/2), which is likely related to light oxidation and iron mineral content.

The peat maturity level at the three locations is generally sapric, meaning mature to very mature peat with a fine structure (Binhar & Sugiyanto, 2020). Fires accelerate the decomposition process through oxidation (Sarifuddin & Akbar, 2024), while in areas without fires, the peat layer structure remains stable. Peat swamps also naturally tend to be sapric due to environmental conditions that support intensive weathering (Nusantara et al., 2016).

Soil water content is a key indicator differentiating the three locations. Peat swamps have the highest water content (1617.46%) due to constant flooding. Unburned land still exhibits natural conditions with a high water content (1076.47%), while burned land experiences a drastic decrease of up to 613.42% due to the heat of the fires evaporating water and damaging soil pores. Ash from the burning also fills the soil pores, reducing its water storage capacity (Hermanto & Wawan, 2017).

Based on Table 2, the bulk density (BD) values at a depth of 0–30 cm in all study locations were relatively low, ranging from 0.12 to 0.13 g/cm³. The highest values were found in peat swamps (0.13 g/cm³), which is thought to be due to natural compaction resulting from water pressure on saturated soil (Nusantara et al., 2016). Conversely, unburned and burned peatlands showed lower BD values, at 0.12 g/cm³. This difference was not significant because both had relatively similar groundwater levels. Low BD values reflect looser soil, so the soil structure in both burned and unburned peatlands is more crumbly than in peat swamps (Rauf, 2016).

Table 3. *Particle density of* peat soil on burned and unburned peatlands

Location	*Particle Density* (g/cm ^{3})	Porosity (%)	Maturity
Peat Swamp	0.77	82.73	Saprik
Burning Peat	0.48	74.50	Saprik
Unburned Peat	0.49	76.35	Saprik

The particle density (PD) value at a depth of 0–30 cm is also very low, ranging from 0.48 to 0.77 g/cm³. Burned peatlands have the lowest *particle density* at 0.48 g/cm³, which is influenced by the decomposition of large peat particles into smaller ones due to the fire, so the density varies depending on the intensity and frequency of the fire. Unburned peatlands have *particle densities* similar to those of burned peatlands, in line with the characteristics of natural peat, which is rich in pure organic matter without mineral admixtures, resulting in low particle density. The high organic matter content is inversely proportional to the particle density value (Afrianti et al., 2019). Peat swamps, on the other hand, exhibit the highest *particle density*, likely due to the accumulation of fine minerals carried by water in saturated soil conditions (Sajarwan et al., 2021).

Soil porosity, which reflects the pore space between particles, also varies between locations. Peat swamps have the highest porosity due to anaerobic and water-saturated conditions that slow decomposition and maintain a loose soil structure (Haq et al., 2025; Nusantara et al., 2012). This high porosity increases the capacity to store water, air, and nutrients (Sa'adah et al., 2025). Unburned peatlands have slightly higher porosity than burned lands. This finding suggests that fires reduce soil porosity due to the loss of structure-forming organic matter, accompanied by the filling of pores by ash from the combustion (Murtinah et al., 2017; Hermanto & Wawan, 2017). Heating from fires can also reduce pore size, making the soil more compact and reducing water storage capacity (Yuningsih et al., 2019). In unburned lands, the soil structure is maintained so that pores remain open and function properly.

3.3. Chemical Properties of Soil

The soil chemical properties observed in burned and unburned peatlands included soil pH and ash content. The analyzed peat chemical properties were obtained from undisturbed soil samples (soil augers) at a depth of 0-30 cm in the upper layers of burned, unburned, and peat swamp peat. The obtained soil chemical properties are presented in Table 4.

Table 4. Soil pH and ash content of peat soil on burned and unburned peatlands

Location	Soil pH	Ash Content (%)
Peat Swamp	3.03 SM	29.06
Burning Peat	2.99 SM	30.76
Unburned Peat	2.86 BC	28.64

Description: SM = Very Sour

Based on Table 4, the pH of peat soil at the three research locations (peat swamp, burned, and unburned) ranged from 2.86 to 3.03, which is considered very acidic. This acidity is closely related to the presence of organic acids resulting from the decomposition of lignin, which produces aliphatic and phenolic acids. Phenolic acids have the potential to inhibit root growth and nutrient availability. The environmental conditions of peat formation also influence its nutrient content (Lestari & Mukhlis, 2021). The study found that peat swamp land had the highest pH (3.03), while burned peat land showed a pH of 2.99, which was higher than that of unburned peat land (2.86). The increase in pH in burned land is influenced by the addition of minerals from ash or charcoal residue from the combustion, particularly alkali oxides, which increase pH. However, under flooded conditions, the dissolution of ash can actually lower the pH again (Arisanty et al., 2020).

Ash content is a parameter that indicates the total minerals or inorganic nutrients remaining after organic soil components are burned at high temperatures. In peat soils, ash content is not only determined by the natural mineral content of the lower layers but is also influenced by surface runoff carrying mineral particles from the surrounding area (Sasli, 2011). Increasing ash content indicates a higher mineral content in the peat, indicating a mixture of inorganic materials. Research results suggest that peat swamps have the highest ash content, likely due to the accumulation of fine mineral particles carried by surface water and continuously deposited under water-saturated conditions. Conversely, unburned peatlands exhibit the lowest ash content. The low ash content in these areas reflects the dominance of organic matter, with little external mineral contamination —a characteristic of oligotrophic peat. In burned peatlands, the loss of top-layer organic matter due to burning is followed by soil compaction. This compaction occurs because the ash from burning organic matter fills the pores in the peat, thereby increasing the soil mass and impacting bulk density (Siregar, 2019).

Field observations at the site of the 2019 fire indicate a natural succession process occurring six years after the incident. The land is currently used for oil palm cultivation and is also covered with various pioneer vegetation, including seduduk, ferns, Litticularia intermedia moss, Leersia oryzoides grass, and Commersonia bartramia shrubs. The fire caused drastic changes to the ecosystem; however, over time, secondary succession has occurred, signalling the land's recovery (Yuningsih et al., 2019). Naturally, peatlands cleared by logging or fire can regenerate through the establishment of pioneer plants such as Melastoma malabathricum, ferns, and other herbs. However, the reappearance of native trees is rare, so the resulting vegetation is generally shrubby (Afitah, 2013).

Figure 2. Research documentations, the condition of peat swamp land (left), the condition of unburned peat land (center), and the condition of burnt peat land (right).

4. Conclusion

The analysis of soil physical properties indicates that all three land conditions—peat swamp, burned, and unburned—are at a sapric maturity level, exhibiting relatively similar physical characteristics. Peat swamp land has higher water content, bulk density, particle density, and porosity compared to the other two conditions. Conversely, burned land shows the lowest water content and porosity. Despite variations in soil color, all sites retain the typical characteristics of peat soil without significant physical alterations.

Field observations at the site of the 2019 fire indicate that six years after the incident, natural succession has occurred, as evidenced by the emergence of pioneer vegetation, including Melastoma malabathricum, ferns, the grass Leersia oryzoides, and the shrub Commersonia bartramia. Currently, the land is also used for oil palm cultivation, so in addition to ecological recovery, the area has economic productivity. Although the fire caused drastic changes to the ecosystem, natural regeneration is generally limited to scrub vegetation, with the return of native trees being rare.

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