Groundwater level response of the primary forest, ex-peatland fire, and community mix plantation in the Kampar peninsula, Indonesia

H Suryatmojo¹*, M A Imron¹, M S Gasa¹, D M Saputra¹ and Maryani²
¹Department of Forest Resource Conservation, Faculty of Forestry, Universitas Gadjah Mada
²Research Center for Disaster, Riau University

*E-mail: hsuryatmojo@ugm.ac.id

ABSTRACT. Indonesia has voluntarily committed to mitigating climate change by reducing its greenhouse gas emissions by 26 percent by 2020 and 41 percent by 2050. More than half of this reduction was originated from the forestry/peatlands sector. Avoiding peat fires is therefore crucial for Indonesia to meet its targets. However, the efforts have been hampered by the fact that a large area of peatland has been burnt. The estimated extent of peatland and mangrove burnt was 2,124,000 Ha during the forest fire in Indonesia in 1997/1998. In 1997-1998, high carbon emissions made Indonesia as one of the largest global polluters. The peat fire occurrence in Indonesia has caused severe problems from environmental, economic, health also mortality. Indonesia has the largest peatland area in the region, which is 20.6 million ha or 10.8% of the land area. These lands are spread across various islands, 7.2 million ha (35%) in the Sumatera island, 6.6 million ha (32%) in Kalimantan island, 0.6 million ha (3%) in Sulawesi island and around 6.2 million ha (30%) in Papua island. Peatland in the Sumatera island has suffered severe damage due to land clearing and burning. The objective of this research is to determine the characteristics of peatland in various land conditions, namely primary forest, ex-peatland fire, and community mix plantation as well as to learn the dynamics of peat groundwater level in each study location. Rainfall and groundwater level sensors installed in the primary forest, ex-peatland fire, and community mix plantation. Rainfall-groundwater level analysis conducted to understand the hydrological response in various peatland characteristics. The results showed that in the ex-peatland fire and mix plantation have changed the peat soil characteristics with an increase of soil bulk density. This indicates decreasing the infiltration capacity, soil porosity and increase the surface water in the peatland area. Increasing the groundwater level response to rainfall is stable in the natural peatland forest. This indicates the function of forest cover as rainfall interception and reduces the volume and lag time of rainwater before reaching the forest floor. Community plantation with low canopy diversity has lower forest cover function than in the natural forest. This will increase the volume of rainwater in the peat soil and increase the rainfall-groundwater level response much higher than in the natural forest. Maintain the diversity of canopy cover and reduce the open peatland by fire will control the hydrological response in groundwater level dynamics.
1. Introduction

Tropical peatland ecosystems play important roles on environmental function and biodiversity conservation. These ecosystems not only serve as reservoirs of freshwater, moderate water levels, reduce storm-flow and maintain river flows, but also help as buffers against saltwater intrusion [1], carbon pool [2, 3, 4] and biodiversity hotspot [5, 6]. Tropical peatlands currently remain a relatively neglected ecosystem with low conservation priority in terms of their intrinsic biodiversity value [6].

Indonesia has the largest peatland in the region, which is 20.6 million ha or 10.8% of the land area. These lands are spread across various islands namely 7.2 million ha (35%) in the island of Sumatra, 6.6 million ha (32%) in Kalimantan, and 0.6 million ha (3%) in Sulawesi and around 6.2 million ha (30%) in Papua. Nearly >50% of peatland in Indonesia belongs to deep peat category that has peat thickness of >200 cm [7].

Peat is a type of soil formed by the accumulation of half-decaying plant remnants; it has high organic matter content and high acidity with brown to blackish features, clay dust texture, unstructured and low nutrient content. This land is known in various countries with various names such as bog, moor, muskeg, pocosin, mire, and in English, it is called as peat [8].

Damage that occurs in peatland ecosystems can be caused by natural factors or human factors. Natural factors are more influenced by climate, while human factors are more influenced by purposeful activities such as land conversion, vegetation burning, activities in utilizing natural resources, canals making on the peatland, and control of unoccupied land.

According to research conducted by Akbar and Ardhana [9] the impacts that can arise as a result of fires are reduced or decreased function of peatlands as water storage, as a result of reduced peat volume, therefore the chance of flooding increases during the wet season, meanwhile during the dry season, the possibility of drought also increases.

Changes in land use from forest land to plantations can also cause the loss of carbon deposits which is currently one of the issues in global warming, the changes in land use from forest to non-forest, especially in peat soils and accompanied by drainage processes resulting in an acceleration in the weathering process, so that carbons stored in peat soils will be emitted in the form of greenhouse gases, especially CO₂ gas [10].

The objectives of this research were to determine the characteristics of peatland in various land conditions, namely primary forest, ex-peatland fire, and mix plantation as well as to learn the dynamics of peat groundwater level in Kampar Peninsula, Riau, Indonesia.

2. Methodology

The research was conducted in 3 locations, namely the primary forest of Zamrud National Park, ex-peatland fire, and community mix plantation in Sungai Rawa Village, Sungai Apit sub-district, Siak district, Riau province. Mini automatic meteorological stations and ground water level sensors was installed at the research sites.

The vegetation profile was measure using Permanent Sample Plot (PSP) of 25m x 80m and in the each corner and the centre of the plot a nested sampling plot is placed to retrieve the seedling growth level density data on a 2m x 2m plot and the sapling density data on a lot with a measurement of 5m x 5m. The collected data included the tree height, branch-free stem height, canopy width for each of the four cardinal directions, stem diameter, type and number of individuals.

The soil data were taken using the disturbed soil sample collection method and the undisturbed soil sample collection method. The disturbed soil sample was taken to obtain data in the form of soil colour and soil maturity level which later were analysed using the van post squeeze method [11] with as many as 3 repetitions for each sample. Each repetition is taken ranging from the top soil, 20 cm, 40 cm and 60 cm. The undisturbed soil sample data collection was using ring and square sample tools. The soil samples obtained will be analysed to acquire the values of water content, porosity, and to find
the value of Bulk Density. The undisturbed soil sample also consisted of 3 repetitions, with the depth starting from the top soil, 20 cm, 40 cm, and 60 cm. In addition to soil samples, which were taken to be analysed in the laboratory, data collection was also carried out by means of a quick probe directly in the field. The data taken were peat thickness by using peat drill, pyrite content using a fast reaction in form of froth by using 30% hydrogen solution (H₂S₂), and also analysing the soil pH using a pH stick. In testing soil samples using the quick probe, 3 repetitions were also performed with the depth starting from the top soil, 20 cm, 40 cm, and 60 cm.

The data of peat groundwater level dynamics and rainfall were obtained from the recording equipment that has been installed for 4 months. The data that has been downloaded were subsequently processed to separate every rainfall event so the dynamics of the groundwater level increasing can be observed. In addition, during the data collection and data downloading, the calibration of peat groundwater level were also carried out manually to match the data between the recorded data with the actual field data so that data can be recorded in accordance with the real condition in the field. The data that has been analysed will be selected with the stipulation that the selected rain event is the rainfall event with Antecedent Precipitation Index (API-3). The aim was to obtain more accurate data and the recorded rainfall data were not affected by the previous rainfall event. The final result was a graph to analyse the impact of rainfall event on the increasing of peat groundwater level in each location.

3. Results and discussion

3.1. Characteristics of peat soil

Tropical peat soil has unique and specific characteristics, related to its content of constituent material, thickness, maturity, and various surrounding environment. The characteristics of peat soil are very different from mineral soil. Specific characteristics of peat soil that are different from the general mineral soil, among other are: easily experiencing irreversible drying, subsidence, low land bearing capacity, low nutrient content, and a limited number of microorganisms [12].

The research sites that are located in primary forest and ex-peatland fire, both have peat soil thickness up to>15 meters, whereas in the mix plantation location the depth is only up to 8 meters. This is evidenced by the peat bomb which has reached and obtained mineral soil samples at the depth of 8 meters.

The peat soil maturity level at the ex-peatland fire and mix plantation site has hemic maturity level starting from the top soil layer up to the depth of 20 cm, while at the location of primary forest the top soil layer up to the depth of 20 cm has a fibric maturity level and at the depth of 40 cm up to 60 cm has a hemic maturity level. This can be caused due to the fibric layer in the upper layer has been lost due to the burning process and the land management process for agricultural and plantation activities. According to Page et al. [13], if the biomass of peat forest plants burned then not only the plant biomass, a few centimetres of the dry peat upper layer will also be burned and will be released into carbon into the air and will cause thinning of the soil layer.

The soil colour at the primary forest is dominated by the 10 R 2.5 / 2 (Very Dusky Red) soil colour, starting from the top soil layer up to the depth of 60 cm. At the ex-peatland fire location, the top soil layer is dominated by the 5 YR 2.5 / 1 (Black) colour and at the depth of 20 cm the colour is 5 YR 3/2 (Dark Reddish Brown), or indicates that the upper layer is darker, which is the impact of land burning. The result of the soil colour analysis at the mix plantation location has the same colour result as the ex-peatland fire, at the top soil layer is 5 YR 2.5 / 1 (Black) colour and at the 20 cm layer is 5 YR 2.5 / 2 (Dark Reddish Brown) colour. According to Suswati et al. [14], the difference in soil colour is generally caused by differences in the organic matter content, the higher the organic matter, the darker the soil colour and the more mature the peat that is formed.

The next peat soil characteristic is pyrite content. In the ex-peatland fire and mix plantation locations, the pyrite content was found at the top soil layer up to 20 cm deep, whereas in the primary forest location, the pyrite content reached 60 cm deep. According to Noor [15], pyrite as a marin
sediment, when oxidized due to a fire event will excessively produce H+ ion so that the pH could decrease and consequently no plants could grow well. Therefore, Ritung et al. [16] state that the presence of water stored throughout the year on peatland is also very important to inhibit the oxidation of pyrite (FeS2) in the mineral soil layer under the peat layer in an effort to reduce soil acidity and plant poisoning.

One of the distinctive Peatland characteristics is a very high acidity level. This is due to the high content of organic acids and hydrogen ions from the weathering organic matter under anaerobic conditions. Based on the research results in the ex-peatland fire and mix plantation locations, they have a pH of 4 starting from the top soil layer up to the depth of 40 cm. In contrast to the primary forest location that shows higher acidity result, namely a pH of 2. This can be caused by land fires and land management into plantations that can increase the pH value to be more alkaline.

Another very distinctive characteristic of peatland is its ability to absorb and store water that is different in every depth. According to Susandi et al. [17], the maximum water binding capacity for fibric peat is 580-3000%, for hemic peat is 450-850%, and for sapric peat is ≤450%. Water content decreases with increasing depth of soil. In the primary forest location, at the depth of 20 cm it has an average water content of around 560.55% to 642.08%, at a depth of 40 cm it is around 388.24% to 660.71%, and at a depth of 60 cm the water content is around 154.74% up to 249.51%. This result is different from the results in the ex-peatland fire, namely, at the depth of 20 cm the average water content is lower, which is around 312.89% to 461.11% and in mix plantation location with the same depth of 20 cm, it has an average water content value of around 183.14% to 471.55%. Land fires and soil cultivation cause changes in soil characteristics; one of which is causing a decrease in the soil ability to absorb water or makes soil to be hydrophobic [18].

Masganti [19] states that porosity will be positively correlated with the depth or the maturity level of peat. The thicker the peat, the less mature the peat is. The less mature the peat, the higher the porosity value, therefore the higher the ability to hold the water. In all locations, namely ex-peatland fire, mix plantation, and primary forest, the results show that the deeper the depth of the peat soil, the lower the value of porosity. In primary forest, the porosity value at the depth of 20 cm, 40 cm, and 60 cm has an average value of around 86.85% - 91.91%; 86.52% - 89.57%; and 60.74% - 87.03% respectively. The ex-peatland fire location has a lower porosity value at the same depth of 20 cm which is around 75.78% - 82.06% on average. In mix plantation location, the porosity value showed lower results compared to the 2 other locations, which is the average value of around 64.68% - 82.49% at the same depth of 20 cm. This can occur due to the process of land burning and land processing for agroforestry which causes soil density to increase which ultimately decreases the porosity value of the soil.

One of the characteristics related to water content and porosity is the BD (Bulk Density) soil characteristic. Nugroho and Widodo [20] state that the weight content of peat in Indonesia, which is between 0.07 to 0.27 g/cm³, is very low compared to mineral soils, ranging from 1.2 to 1.8 g/cm³. In primary forest land, the values of BD starting from the depth of 20 cm, 40 cm, and 60 cm respectively have an average value of around 0.11 - 0.13; 0.14 - 0.15; and 0.15 - 0.24. From the data obtained it can be observed that the BD value will increase with the increasing soil depth and the decreasing porosity value and the increasing maturity of the peat soil. The research results in the ex-peatland fire and mix plantation location have a higher BD value at the same depth of 20 cm. In the ex-peatland fire location, the average BD value is around 0.17 - 0.19 and in the mix plantation location, the average value is around 0.15 - 0.21. Soil compaction or soil enhancement can occur as a result of land burning processes and as a result of human activities in processing peatland into plantation land.

3.2. Vegetation in research locations

In the permanent sample plot (PSP) of primary forest, the vegetation is still very natural because the location is located in the national park area. The vegetation structure in the primary forest can be seen from the results of the analysis using the SexiFS software (Figure 1).
In term of the number of species in the PSP, there are about 8 species of woody plants with the largest stem diameter of about 89 cm. These plant species include *Ficus sp.*, *Litsea citrata*, *Palaquium burckii*, *Palaquium sp.*, *Parastemon urophyllum*, *Shorea uliginosa*, *Tetramerista glabra*, and *Vatica walichii*. But most of the plants in PSP are dominated by the *Parastemon urophyllum* species. The density values for each growth level can be seen in Table 1.

| Growth Level | Density (Ind/2000m²) | Density (Ind/Ha) |
|--------------|----------------------|------------------|
| Seedling     | 2000                 | 10000            |
| Sapling      | 656                  | 3280             |
| Pole         | 38                   | 190              |
| Tree         | 50                   | 250              |

The results indicate that the density of the seedling growth level reaches is about 10,000/ha. This indicates that the growth of fallen and mature seeds is very good and the environmental condition allows the seeds to grow well into seedlings. The sapling growth level is about 3280/ha, then the pole growth level is about 190/ha and the last one is the tree growth level is about 250/ha.

In the PSP of ex-peatland fire, most vegetation has been lost due to the burning process, so there is only a small amount of vegetation that survived in the research location. The profile diagram in the PSP is presented below (Figure 2).

The measurement result in the PSP indicates that there are only 3 individual trees and 1 individual pole in the PSP. Consequently, in hectares, the number of trees is only 15/ha while the number of the pole is only 5/ha. These species include *Acacia crasicarpa* and *Elaeis guinensis*. The density values for each growth level can be seen in Table 2.
In the PSP of mix plantation, the vegetation composition is designed by the community based on their purposed need. The results in the PSP found rubber (*Elais guinensis*) with 18 trees, guava (*Syzigium sp.*) with 5 trees, and palm oil (*Heve brasiliensis*) with 78 trees. The profile diagram in the PSP is presented below (Figure 3).

![Image](image_url)

**Figure 3.** Profile diagram of mix plantation, vertical (left) and horizontal (right)

The measurement result in the field shows the density value at each growth level and the type. These values can be seen in Table 3.

| Growth Level | Density (Ind/2000m$^2$) | Density (Ind/ha) |
|--------------|-------------------------|-----------------|
| Seedling     | 0                       | 0               |
| Sapling      | 0                       | 0               |
| Pole         | 1                       | 5               |
| Tree         | 3                       | 15              |

**Table 3.** Vegetation density based on growth level in the mix plantation

3.3. The dynamics of peat groundwater level

In this research, rainfall data is used as the independent variable which would be analysed in relation to the response of peat groundwater level (GWL) increase as the dependent variable. The selected rainfall events which on the previous 3 days there was no rain in the location or Antecedent Precipitation Index (API-3). It is intended so that the rainfall measured on that day is not affected by the previous rainfall. Based on the selected data during the observation, the primary forest research location (Table 4) has a total of 5 rainfall events with API-3.
The primary forest shows that the highest rainfall data only at 42 mm which raises the groundwater level by 6.2 cm while the lowest rainfall is 1.5 mm caused the GWL increase by 0.7 cm. The ex-peatland fire is included in the category of mild to moderate daily rainfall intensity.

Table 4 shows that high rainfall does not always raise the GWL to reach the ground surface. For example, in the rainfall event of 42 mm, it is able to increase the peat GWL up to 6.2 cm but the GWL is still on 7.3 cm below the ground surface. It means that it has not been able to raise the GWL high enough to cause flooding, whereas in the fourth rain event with 1.5 mm, it is only able to raise the peat groundwater level by 0.7 cm, yet the peat GWL is able to reach the height of 11.4 cm above ground surface, which means that there is an abundance of water over the surface or it can be interpreted that the primary forest experiences 11.4 cm of water flooding.

Such a condition can be caused by the saturation level of the soil. If the soil has a high level of drought it is necessary to have high rainfall to increase the peat groundwater level. This is because the rain water has to fill a lot of empty space on the peat soil. If the soil is already saturated, small to moderate rainfall intensity will be able to raise the water table level to exceed the ground surface.

If this condition is associated with the existing vegetation, tropical peat in general, including those in Sumatra and Kalimantan, are continuously wet with the water table level above or near the peat surface. This is supported by Driessen's [21] study in Wahyunto et al. [7] in peat swamp forest areas that are still intact and still has its original vegetation cover (virgin forest), the water table fluctuations at the centre of the peat dome is 19 cm while at the edge of the dome is 10 cm. The trees in peat areas that are still forested still function to maintain the balance of groundwater level through a slow and balanced evapotranspiration process. Besides that, environmental factors such as the buffer effect of porous peat, lateral permeability of fibric peat in the centre of the dome, intensive surface flow through small trenches and connecting flow allow abundant water release on the edge of the dome, which is immediately followed by the inner dome (due to its porous nature) from time to time which can usually be observed during rainy days.

As the result of a simple analysis between the rain thickness and the increase of water table level in the primary forest location, an R² value of 0.5982 (Figure 4) was obtained. This means that the rainfall correlates and has a very strong impact on the increase in the peat GWL. The rainfall impact on the peat GWL response was 59.82%, while the rest was influenced by other variables or factors.

Based on the available data, the research location in the ex-peatland fire (Table 5) has a total of 8 rainfall events with a time span of no rainfall for 3 days (API-3). Table 5 shows the number of rainfall event as much as 8, the highest rainfall reached 33.6 mm and it was able to increase the GWL by 40.2 cm. Whereas the lowest rainfall data in the ex-peatland fire location is 2 mm that was able to increase the peat GWL by 1.4 cm. The ex-peatland fire location is included in the light to heavy daily rainfall intensity category. Looking at the response of the GWL by the rainfall events, there are 6 rainfall events out of a total of 8 rainfall events over 4 months that can raise the peat GWL to exceed the ground surface which is interpreted as stagnant or flooded water. The rainfall value that caused flooding occurred in the rainfall of 33.6 mm with an increase GWL of 40.2 cm which caused the flooding to reach 16.9 cm above the ground surface.

**Table 4. Selected rainfall events with API-3 in the primary forest location**

| Rain Event | Date/Month | Rainfall (mm) | Increase GWL (cm) | GWL (cm) |
|------------|------------|---------------|-------------------|----------|
| 1          | 10/02      | 42            | 6.2               | 7.3      |
| 2          | 14/03      | 4.4           | 3.5               | -0.3     |
| 3          | 23/04      | 9.3           | 2                 | 3.2      |
| 4          | 28/04      | 1.5           | 0.7               | -11.4    |
| 5          | 27/05      | 5.3           | 0.7               | 3.8      |
Figure 4. Graphic of the increase GWL response in the primary forest

Table 5. Selected rainfall events with API-3 in the ex-peatland fire

| Rainfall Event | Date/ Month | Rainfall (mm) | Increase GWL (cm) | GWL (cm) |
|----------------|-------------|---------------|-------------------|----------|
| 1              | 10/02       | 6.3           | 5.5               | -45.8    |
| 2              | 1/03        | 3.4           | 2                 | -18.8    |
| 3              | 7/03        | 2             | 1.4               | -6.4     |
| 4              | 29/03       | 21.6          | 19.3              | -10.5    |
| 5              | 31/04       | 6.8           | 7.6               | -2.9     |
| 6              | 8/05        | 33.6          | 40.2              | -16.9    |
| 7              | 14/05       | 6.7           | 14.5              | 19.9     |
| 8              | 23/05       | 13            | 27.7              | 12.3     |

Table 5 shows that high rainfall does not always raise the GWL to exceed the ground surface. For example, on the rainfall of 13 mm that categorized in the medium rainfall intensity, it can increased the peat GWL up to 27.7 cm but the peat GWL is still on 12.3 cm below the ground surface which means that it has not been able to raise the GWL high enough to cause flooding. Whereas in the rainfall event of 2 mm that is categorized of light rainfall, it is able to increase the peat GWL by 1.4 cm, but it was able to reach the height of 6.4 cm above the ground surface and it abundance of water over the surface or experiences flooding as high as 6.4 cm.

Such a condition can be caused by the saturation level of the soil. If the soil has a high level of drought it is necessary to have high rainfall to increase the peat GWL. This could happen because the rain water has to fill a lot of empty pores space on the peat soil. When the soil is saturated, even though the rainfall categorized in small to moderate, it is able to raise the GWL to exceed the ground surface. Referring to the research conducted by Firmansyah and Mokhtar [22], peat soil is a soil that is prone to fire during the dry season. In the dry season, peatland generally experiences drought in the surface layer, causing a decrease in groundwater level and during the rainy season usually the ex-peatland fire will usually experience flooding due to many factors, one of which is the absence of vegetation that maintains the hydrological cycle in the area.

The result of simple regression analysis between the rainfall and the increase of GWL on the ex-peatland fire location is shown in Figure 5. The graph shown the $R^2$ value of 0.8737 was obtained.
This means that the rainfall correlates and has a very strong impact on the increase in GWL. The rainfall impact on the peat GWL response was 87.37%, while the rest is influenced by other variables or factors.

![Graph of GWL response](image)

**Figure 5.** Graphic of the increase GWL response in the ex-peatland fire

In the mix plantation location, there were 7 selected rainfall events with the highest rainfall of 33.6 mm and that was able to increase the peat GWL by 2.7 cm, while the peat GWL was 6 cm below the ground surface (Table 6). In contrast, the lowest rainfall of 2 mm caused no increase in the peat GWL, while the peat GWL is able to exceed the ground surface of about 5.1 cm. This condition can be caused by the saturation level in the soil.

**Table 6.** Selected rainfall events with API-3 in the mix plantation

| Rainfall Event | Date/Month | Rainfall (mm) | Increase GWL (cm) | GWL (cm) |
|----------------|------------|---------------|-------------------|----------|
| 1              | 08/04/2018 | 2             | 0                 | -5.1     |
| 2              | 21/4/2018  | 15.3          | 1.4               | 14.3     |
| 3              | 29/4/2018  | 6.7           | 0.7               | 9.4      |
| 4              | 06/05/2018 | 21.1          | 2.8               | 15.7     |
| 5              | 29/5/2018  | 5.3           | 0                 | -2.3     |
| 6              | 04/06/2018 | 22.2          | 1.3               | 8.7      |
| 7              | 08/06/2018 | 33.6          | 2.7               | 6        |
The result of a simple regression analysis between the rainfall and the increase of GWL in the mix plantation location is shown in Figure 6. The graph shown the R² value of 0.7985 was obtained. This means that the rainfall correlates and has a very strong impact on the increase in GWL. The rainfall impact on the peat GWL response was 79.85%, while the rest is influenced by other variables or factors.

4. Conclusion

Changes in land conditions that occur on peatland both caused by fire and land processing into plantation cause changes in soil characteristics including the increase in the Bulk Density, decrease the soil porosity and the ability to store water, and increase in pH values, and siltation/decrease in peat soil layer which ultimately decreases the function of peatland. The final impact is excessive land drought during the dry season and water flooding during the rainy season. The rainfall parameter has a very strong positive correlation with the increase in peat groundwater level in the ex-peatland fire, mix plantation, and the primary forest locations. Controlling the peat land cover by vegetation, peat soil disturbance and peat groundwater level could maintain the hydrological process in the peat soil.

References

[1] Wösten, J. H. M., E. Clymans, S. E. Page, J. O. Rieley, and S. H. Limin. 2008. Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia. CATENA 73:212–224.
[2] Page, S. E., J. O. Rieley, and C. J. Banks. 2011. Global and regional importance of the tropical peatland carbon pool. Global Change Biology 17:798–818.
[3] Ballhorn, U., F. Siegert, M. Mason, and S. Limin. 2009. Derivation of burn scar depths and estimation of carbon emissions with LIDAR in Indonesian peatlands. Proceedings of the National Academy of Sciences 106:21213–21218.
[4] Hirano, T., H. Segah, K. Kusin, S. Limin, H. Takahashi, and M. Osaki. 2012. Effects of disturbances on the carbon balance of tropical peat swamp forests. Global Change Biology 18:3410–3422.
[5] Posa, M. R. C. 2011. Peat swamp forest avifauna of Central Kalimantan, Indonesia: Effects of habitat loss and degradation. Biological Conservation 144:2548–2556.
[6] Rose, M., C. Posa, L. S. Wijedasa, and R. T. Corlett. 2011. Biodiversity and Conservation of Tropical Peat Swamp Forests. BioScience 61:49–57.

[7] Wahyunto, Ritung, Sukarto, and Subagio, H., 2005. Sebaran Gambut dan Kandungan Karbon di Sumatera dan Kalimantan. Proyek Climate Change. Forests and Peatlands in Indonesia. Wetland Int’l – Indonesia Programme and Wildlife Habitat Canada (Bogor) p. 254

[8] Barchia, 2012. Gambut, Agroekosistem, dan Transformasi Karbon (Yogyakarta: Gadjah Mada University Press)

[9] Akbar A, Junaidah and Ardhana, A. 2006. Restorasi Lahan Gambut Bekas Terbakar Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan. (Banjarbaru)

[10] Triyono D 2015 Strategi Pengembangan Kelapa Sawit lahan Gambut Kabupaten Kubu Raya. 4 pp 40–48

[11] Notohadiriprawiro, T., 1983. Selidik Cepat Ciri Tanah di Lapangan Laboratorium Pedologi Jurusan Ilmu Tanah Fakultas Pertanian Universitas Gadjah Mada. (Jakarta: Gahlia Indonesia)

[12] Anonymous, 2003. Key to Soil Taxonomy. 9th Edition. (United States Department of Agriculture Natural Resources Conservation Service)

[13] Page S E, Siegert F, Rieley J O, Boehm H D V, Jaya A, and Limin, S. H., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997 Nature 420 pp 61-65.

[14] Suswati D, Hendro B, Shiddieq D, and Indradewa, D., 2011. Identifikasi Sifat Fisik Lahan Gambut Rasau Jaya III Kabupaten Kubu Raya Untuk Pengembangan Jagung. Jurnal Perkebunan dan Lahan Tropika, 1: 3140 (Riau)

[15] Noor, M., 2001. Pertanian Lahan Gambut Potensi dan Kendala (Yogyakarta: Kanisius)

[16] Ritung, S., Wahyunto, K., Nugroho, Sukarman, Hikmatullah, Suparto, dan C. Tafakresnanto., 2011. Peta Lahan Gambut Indonesia Skala 1:250.00. Balai Besar Litbang Sumberdaya Lahan Pertanian. Bogor, Indonesia.

[17] Susandi, Oksana, and Arminudin A. T., 2015. Analisis Sifat Fisika Tanah Gambut Pada Hutan Gambut Di Kecamatan Tambang Kabupaten Kampar Provinsi Riau Jurnal Agroteknologi. Vol. 5 (2) Agroteknologi Fakultas Pertanian Dan Peternakan UIN Sultan Syarif Kasim. Riau

[18] Masganti, 2006. Sample preparation and hydrophobic of peat material Tropical Peatlands. 6(6) pp. 10-14

[19] Masganti, 2003. Kajian Upaya Meningkatkan Daya Penyediaan Fosfat dalam Gambut Oligotrofik Dissertation UGM Postgraduate Program (Yogyakarta) p 355

[20] Nugroho K. and Widodo B., 2001. The effect of dry-wet condition to peat soil physical characteristic of different degree of decomposition pp 94-102 In Rieley, and Muhammad Noor, Masganti, F Ahmadin Agus Page (Eds.) Jakarta Symp. Proc, on Peatlands for People: Nat. Res. Funct. and Sustain. Manag

[21] Driessen P. M., 1980. Problem Soils: Their Reclamation And Management pp 53-57 In Wahyunto, Ritung S, Suparto, and Subagyo H 2005 Sebaran Gambut dan Kandungan Karbon di Sumatera dan Kalimantan 2004 Wetlands International – Indonesia Programme and Wildlife Habitat Canada (Bogor)

[22] Firmansyah M A and Mokhtar M. S., 2012. Profil ICCTF di Kalimantan Tengah: pengelolaan lahan gambut berkelanjutan. BPTP Kalimantan Tengah p. 30