Buletin Poltanesa Vol. 26 No. 2 (December 2025) 00-00 p-ISSN 1412-0097 e-ISSN 2614-8374
https://doi.org/10.51967/tanesa.v26i2.3601 © 2025 Politeknik Pertanian Negeri Samarinda

PM2.5 and CO Concentrations from Peatland Forest fires 2023 in Central Kalimantan, Indonesia

Kitso Kusin *
Forestry, University of Palangka Raya, Palangka Raya, 73111, Indonesia
kitso@for.upr.ac.id
**Corresponding author*

Patricia E. Putir
Forestry, University of Palangka Raya, Palangka Raya, 73111, Indonesia
patricia@for.upr.ac.id

Sampang Gaman
Forestry, University of Palangka Raya, Palangka Raya, 73111, Indonesia
sampang@for.upr.ac.id

Alpian
Forestry, University of Palangka Raya, Palangka Raya, 73111, Indonesia
alpian@for.upr.ac.id

Wahyu Supriyati
Forestry, University of Palangka Raya, Palangka Raya, 73111, Indonesia
wahyu.supriyati@for.upr.ac.id

Adi Jaya
Agrotechnology, University of Palangka Raya, Palangka Raya, 73111, Indonesia
adijaya@agr.upr.ac.id

Submitted: 2025-11-21; Accepted: 2025-12-16; Published: 2025-12-20

***Abstract*—** Peatland Forest fires are one of the main causes of high concentrations of particulate matter and gases, especially PM2.5 and carbon monoxide (CO). Particles of PM2.5 are very small, so they can enter directly into the human lungs, as well as high concentrations of CO will affect the concentration of carboxyhemoglobin (COHb) in human blood, so it can cause decreased vision, hearing, and death. Monitoring of particulate and gas concentrations is carried out, to increase the concern of all levels of society, so as not to burn forests and peatlands in the dry season, be careful in carrying out all activities outside the home during peatland forest fires, especially vulnerable ages such as infants, children, pregnant, people with congenital diseases and the elderly. The sensor tools used are P-Sensor for recording PM2.5 concentration and EL-USB-CO sensor for recording carbon monoxide (CO) concentration placed at UPT Laboratorium Lahan Gambut – CIMTROP University of Palangka Raya and north-west at PERUM PEMDA Km 10 Cilik Riwut, Palangka Raya for 2 months during forest and peatland fires in September and October 2023. Data is tabulated and analyzed using Microsoft Excel. T-test result of PM2.5 and CO concentration during the rainy season and dry season (peatland forest fire) is p-value < 0,05 at UPT LLG – CIMTROP dan Perum Pemda Km 10 Cilik Riwut. The PM2.5 concentration in UPT LLG – CIMTROP during the peatland forest fires 2023 is 700.24 μg/m^3, while the CO concentration is 7,446 μg/m^3 (6.5 ppm). The PM2.5 concentration at the PERUM PEMDA Km 10 Cilik Riwut is 333.39 μg/m^3, while the CO concentration is 26,439 μg/m^3 (23 ppm). PM2.5 concentrations in UPT LLG – CIMTROP are higher, but CO concentrations are lower than those in PERUM PEMDA Km. 10 Cilik Riwut, possibly caused by wind direction effect, vegetation, fuel, and other sources such as vehicle fumes in respective locations.

***Keywords*—** Peatlands Fire, Dry Session, Particulate Matter, Gases Concentration, Vulnerable Ages

I. INTRODUCTION

Central Kalimantan's has long history of peatland forest fires that occur in every dry season (El Nino), recorded from 1972 – 2006, then continued in 2009, 2014, 2015, 2019 (Kusin, *et al.*, 2022a) and finally in 2023. The forest fires caused by various factors, including climate (Field, et al., 2016), vegetation, human activities, and land use (Schmidt, et al., 2024). The losses caused by peatland forest fires are enormous, especially those related to the area burned. LAPAN (2015), in 2015 reaching 190,000 ha. DPKHL (2020), in the period 2015-2020 the burned area reached an area of 964,587.25 ha. Volkova, et al., (2021b), at degraded forest Central Kalimantan in 2019 reached 133,631 ha. The result of these peatland forest fires is smoke containing harmful particles and gases to living things, potentially detrimental to respiratory outcomes, when near (Uttajug, *et al.*, 2021) and distant (Tajudin, *et al*., 2024) to the burning location, but remain detrimental even after being transported over distances (Sulong, *et al.*, 2017). The life time at atmospheric greenhouse gases is shorter, but these particles affect the earth's system as well as the environment for at least a short time (Kuwata et al, 2018).

Peatland fires in forests are a big problem for air pollution (Schmidt, et al., 2024). Smoke from these fires creates very high levels of particulate matter (PM), which causes haze (Madrigano, *et.al*., 2024). This haze affects air quality in the surrounding areas. The mix of weather conditions and how the fires behave, like how wet or dry the area is, how hot it is, what kind of plant material is burning, and whether the fire is smoldering or flaming, all lead to different types of emissions and various chemicals being released (Black, et al., 2017; Sulong, et al., 2017;

Stockwell, et al., 2016). Kusin, *et al.*, (2022a), the concentration of PM2.5 in the air due to forest and peatland fires in 2019 was 196.8 – 360.5 μg/m^3, while the concentration of CO was 7104.1 – 22,127.5 μg/m^3. The concentration of these particles and gases is very high and very dangerous for humans, especially in people who are susceptible to exposure such as; infants, children, pregnant women, and the elderly.

Particles of PM2.5 is very small (2.5 μm) can go deep into the lungs and into the bloodstream. Breathing air with high levels of particulates can damage the upper and lower respiratory tracts, resulting in inflammation of the airways and conditions such as coughing, bronchitis, breathing difficulties, reduced lung function, and eventually more severe obstructive respiratory distress Chretien, *et al*., (1996). Short-term exposure will exacerbate pre-existing disease (Xing, *et al.*, 2015; Khaniabadi, *et al.*, 2016), between 6,513 and 17,270 causing premature death (Crippa, 2016). Long-term exposure can cause disease, even premature death, premature death as much as 100,300 (Koplitz, 2016), impact on human physiology, such as spurring inflammation and blood coagulation; respiratory, cardiovascular, and autonomic nervous system disorders; as well as an increased risk of genetic mutations (Williamson, *et al*., 2016).

The concentration of CO in the air greatly affects the concentration of carboxyhemoglobin (COHb) in human blood. An increase in COHb levels of 2-20% leads to decreased vision, hearing, motor, and sensorimotor performance as well as brain and nerve performance (Townsend, 2002).

Monitoring PM2.5 and CO concentrations is very important, to increase the awareness of all levels of society, so as not to burn peatlands and forest in the dry season, be careful in carrying out all activities outside during the peatland forest fires, especially vulnerable ages such as infants, children, pregnant women, people with congenital diseases and the elderly.

II. LITERATURE REVIEW

A. Peatland forest fires

The occurrence of forest and peatland fires in Central Kalimantan due to the rampant cleaning and land conversion activities accompanied by the construction of canals/drainage to dry peat, is also supported by extreme El Nino weather. Forest and peatland fires cause thick haze for months and impact the economy, social, health and even one of the smog-contributing provinces to neighboring countries.

The process of burning peat with limited oxygen (pyrolysis) in the second stage is to heat the peat continuously to 260°C to gradually increase the pyrolysis speed, with hemicellulose and cellulose decomposing into gases as CO2, CO, CH4, CH3OH, CH3COOH and laevoglucose (Usup et.al., 2004). Levoglucosan is a major component in the form of a viscous liquid that is widely used as an artificial pesticide.

Haze also contains volatile gases and fine particles (PM) which have a very short lifespan in the atmosphere but greatly affect the earth system and the environment (Kuwate et al, 2018). Forest and peatland fires also lead to reduced visibility and severe air pollution (Lee et al., 2017), as well as increased disease and mortality rates (Crippa et al., 2016).

B. Particulate matter

The main constituent particles of biomass combustion are PM2.5 which has an aerodynamic diameter of below 2.5 μm, this particle greatly affects health (Schlesinger, 2007). Incomplete fires from peat fires emit haze, containing fine and coarse particles and toxic gases (Stockwell, et al. 2016), are the dominant source of PM2.5 emissions, accounting for 55% of all fire sources (Fujii, et al., 2014). Approximately 80 - 90% of smoke particles are within the PM2.5 size range, these particles are derived from organic carbon, which constitutes 50 - 60% of the total mass of particles (Phuleria et al., 2005; Reid et al., 2005).

Smoke from forest and peatland fires is a significant source of air pollution linked to harmful impacts on human health and the environment (Uda, 2019). Some researchers estimate PM2.5 concentrations from peat fires to be 21.5 ± 4.6 g/kg (Stockwell, et al. 2016) 34.4 ± 18.8 g/kg, (Wooster et, al., 2018), 17.3 ± 6.0 g/kg (Jayarathne et al., 2018), 7.33 Tg from fires in Sumatra and Kalimantan during September – October 2015 (Kiely, et al., 2019).

C. Carbon monoxide

Smoke from fires contains about 90% of the carbon emitted either as carbon dioxide (CO2) or carbon monoxide (CO) depending on the type of fuel and combustion efficiency (Andreae and Merlet, 2001). The life span of carbon monoxide in the air is approximately 2 months but it is very effective in reducing environmental quality and health (Edwards, 2006).

The 2014 fire in Pekanbaru showed a significant effect of increasing PM10/CO values of 82-127 μg mg-1, compared to Muar of only 17-36 μg mg-1. This is because in Pekanbaru it is a peatland fire located downstream of the observation location, while in Muar it is more influenced by forest fires that are not peat (Kuwata, et al, 2018). Huijnen, et al (2016), the total carbon released from the fires in the September-October 2015 period was 227 ± 67 Tg C, of which 83% was in the form of CO2 (692 Tg CO2), 16% CO (84 Tg CO), and 1% CH4 (3.2 Tg CH4). Konecny et al., (2016) predicted that the carbon released into the air from the former Mega Rice Project (MRP) area of Kapuas Regency was 229 tons/ha. Kawasaki, et al, (2019), the concentration of CO in forest and peatland fires in Palangka Raya in 2019 increased in the second week of August and the third week of September to 14 ppm.

III. METHODS

A. Study site

This research was carried out in Palangka Raya for 2 months during the rain season in May and June and 2

months in dry season during the peatland forest fires in September and October 2023.

Sensors installed at UPT Laboratorium Lahan Gambut – CIMTROP University of Palangka Raya and north-west in the PERUM PEMDA Km. 10 Cilik Riwut, Bukit Tunggal, Jekan Raya District, Palangka Raya City (Figure 1). These two locations were chosen to represent the exposed areas (UPT LLG) because they are close to the fire site and affected by haze (Perum Pemda Km.10) which is far from the fire site.

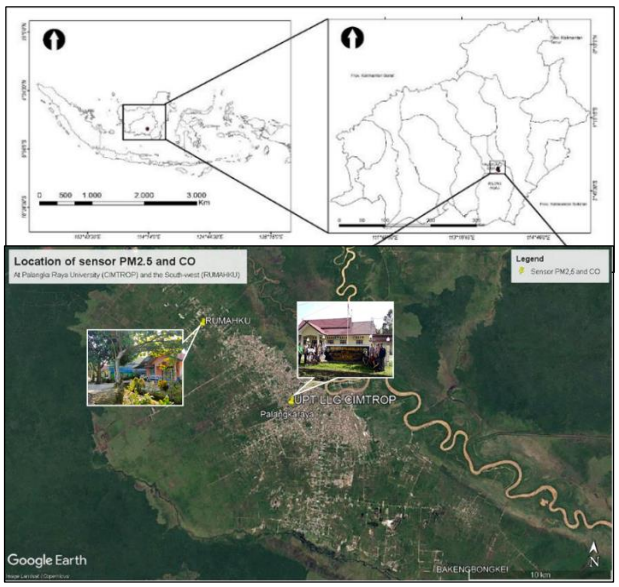

Figure 1. Location of CO and PM2.5 sensor are placed

B. Data analysis

Data is tabulated, analyzed presented in the form of graphs using Microsoft Excel. The t-test is performed to see the difference in PM2.5 and CO concentrations in the rainy season and dry season. The sensor tools used are P-Sensor for PM2.5 concentration recorder (Figure 2) and EL-USB-CO sensor for carbon monoxide concentration recorder (Figure 3). These two sensors are not calibrated because they have an active period of 3 years, after which they are no longer used.

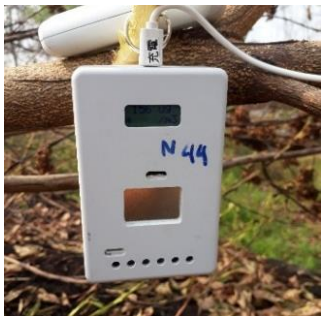

Figure 2. P-Sensor

Figure 3. EL-USB-CO

IV. RESULTS AND DISCUSSION

The results of the PM2.5 concentration t-test at UPT LLG – CIMTROP UPR (Figure 4) and Perum Pemda Km. 10 Cilik Riwut (Figure 5) between the rainy season and the dry season (forest fire) showed a p-value of < 0.05, which means that there is a significant difference that PM2.5 concentration is higher during the dry season.

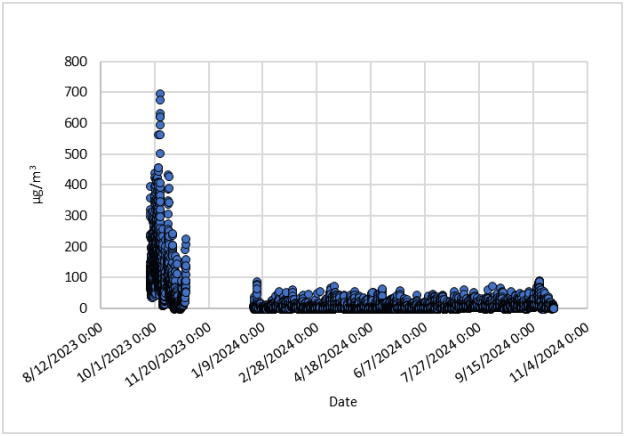

Figure 4. Concentration of PM2.5 at UPT LLG – CIMTROP

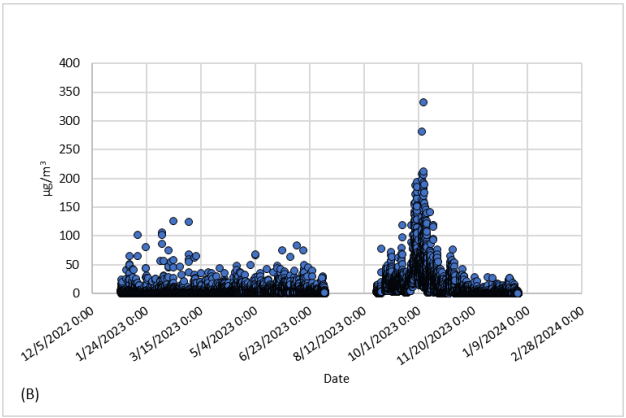

Figure 5. Concentration of PM2.5 at Perum Pemda Km. 10 Cilik Riwut

PM2.5 concentrations during the rainy season until June is low, entering the dry season in August, September, and October at the monitoring location UPT LLG - CIMTROP UPR on October 6, 2023 reached to 700.24 µg/m^3 and at the monitoring location Perum Pemda Km. 10 Cilik Riwut on October 5, 2023 reached to 333.39 µg/m^3, then fell at the end of October along with rain in several locations (Figure 6). Peatlands forest fires more occurred in the southwest area, smoke pollutants of peatland forest fires moving upwind past monitoring sensors from south to north at the UPT LLG CIMTROP, then spreads and changes direction to east (Figure 7 and Figure 8). Palangka Raya City is downwind of Pulang Pisau Regency during the southwest monsoon, a dry season that makes it easier for fires to start and spread. During the monsoon season, which was from July to September in 2015 and 2019. So, the high levels of

PM10 in Palangka Raya City might include some pollution carried in from fires in areas upwind. This could be a reason for the high risk of breathing problems on haze days, even if there are not many fires happening locally (Phung, et al., 2025). Pulang Pisau Regency is a major burning area in Central Kalimantan (Akbar, 2022; Yulianti, et al., 2020a), although burnings could be dominant in Palangka Raya City irregularly, particularly due to prescribed fires (Yulianti, et al., 2020b).

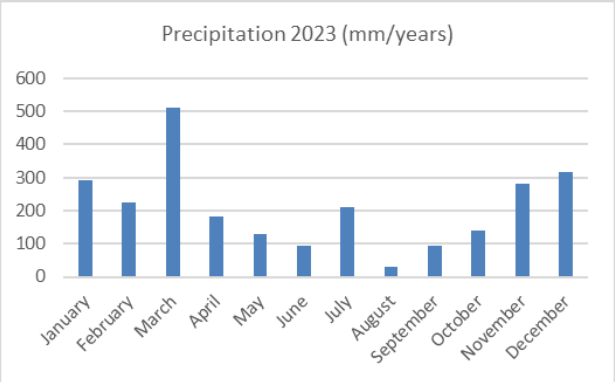

Figure 6. Precipitation at Palangka Raya 2023 (bmkg.go.id)

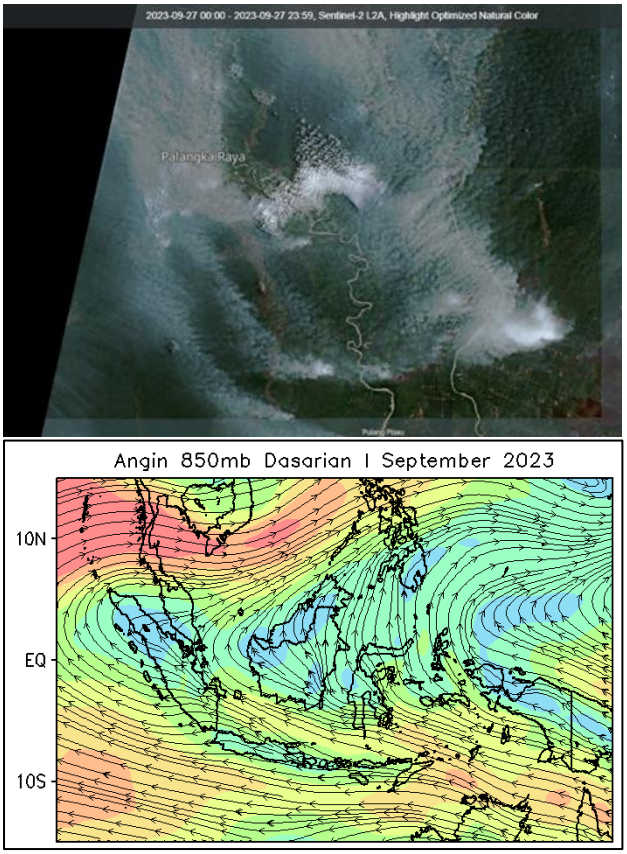

Figure 7. Smoke and wind distribution at Palangka Raya city area (Sep 27, 2023) (https://apps.sentinel-hub.com and bmkg.go.id)

The difference concentration between the two locations is due to factors such as wind direction and distance from the fire location (Kusin, *et al.*, 2022a), the morphology of plants growing around the site, climatic conditions, such as rain and wind, and the composition of PM itself (Yulianti, 2011), as well as the occurrence of large peatland forest fires in the Perum Pemda area Km. 10 Cilik Riwut is less than peatlands forest fire area at the UPT LLG CIMTROP.

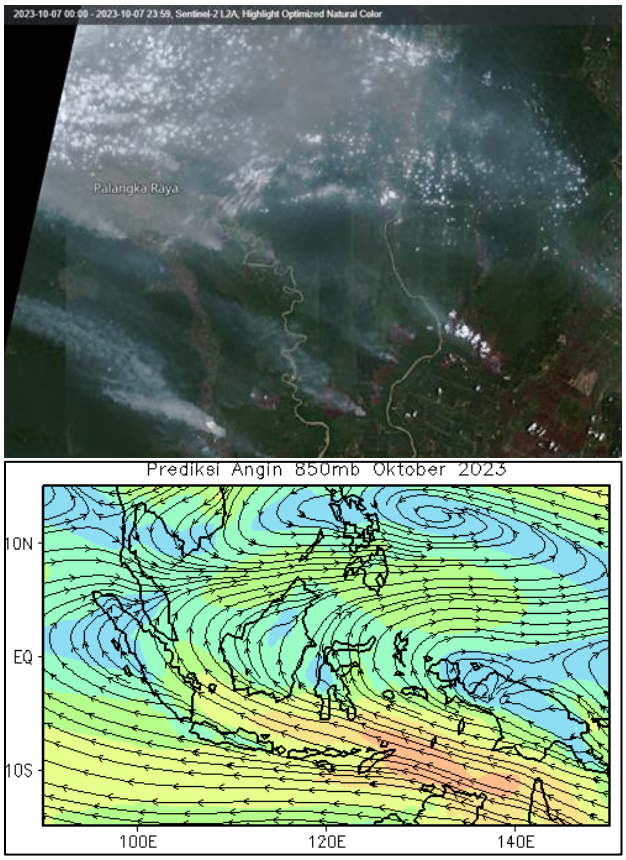

Figure 8. Smoke and wind distribution at Palangka Raya city area (Oct 7, 2023) (https://apps.sentinel-hub.com and bmkg.go.id)

The mix of different climate conditions and fire features, like moisture levels, heat, types of plant material, and whether the fire is smouldering or flaming, causes the release of various forms and chemicals (Black, *et al*., 2017; Sulong, et al., 2017; Stockwell, et al., 2016). On the south area peat depth >300 cm (CIMTROP, 2017), there is an incomplete combustion that emits thick smoke when the peatlands forest fire, starting with the burning of vegetation that grows on it after which it spreads vertically downwards to a certain point (depending on the humidity and groundwater conditions) and horizontally, this process will last for a very long time (Figure 9). The vertical spread of peat fires reaches 54 cm (Kusin, et al., 2020). Compared to the northern part (Perum Pemda Km. 10 area), peat depth of ± 50 cm, the material under the peat is sand (Figure 10), the vertical burning process will stop after reaches the lower layer, but continue horizontal burning process.

Figure 9. Peatlands forest fires at south area

Figure 10. Peatlands forest fires at north area

The The results of the CO concentration t-test at UPT LLG – CIMTROP (Figure 11) and at Perum Pemda Km. 10 Cilik Riwut (Figure 12) between the rainy season and the dry season (forest fire) showed a p-value of < 0.05, which means that there is a significant difference that CO concentration is higher during the dry season.

The concentration of CO at UPT LLG – CIMTROP UPR on the rainy season is low and the beginning of the dry season still in the low category, then began to rise to the medium category of 7,446 µg/m^3 (6.5 ppm) on October 2, 2023, while the CO concentration in Perum Pemda Km. 10 Cilik Riwut is different, at the beginning of September it rose to the dangerous category of 26.439 µg/m^3 (23 ppm), then slowly descending to the low category. This case also showed that at the beginning of peatland forest fires 2019 were quite high reaching 8793.2 µg/m^3, then slowly fell to the low category. The cause is the difference in fuel, burned area, vegetation, and wind (Kusin, *et al*., 2022a). Vehicle fumes are also the cause of increased CO concentrations, industrial activities, local combustion, and various agricultural activities. The highest concentrations of gases and particles tend to be in the dry season, but places with strong winds and low temperatures, the concentration of gases and particles will decrease (Kumar, 2013). Other case, location of UPT LLG CIMTROP in the Palangka Raya University with more crowded people and transportation then Perum Pemda Km. 10 Cilik Riwut location is far from the city and more vegetation around.

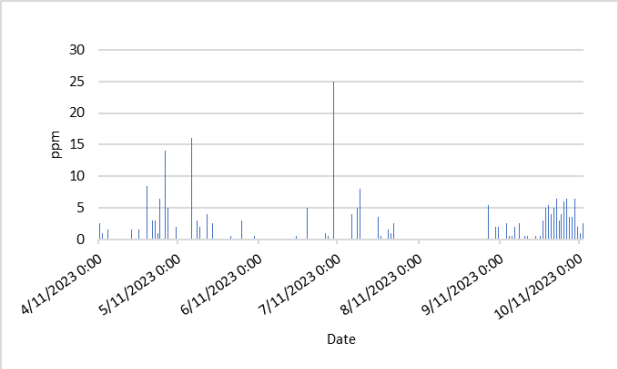

Figure 11. Concentration of CO at UPT LLG – CIMTROP

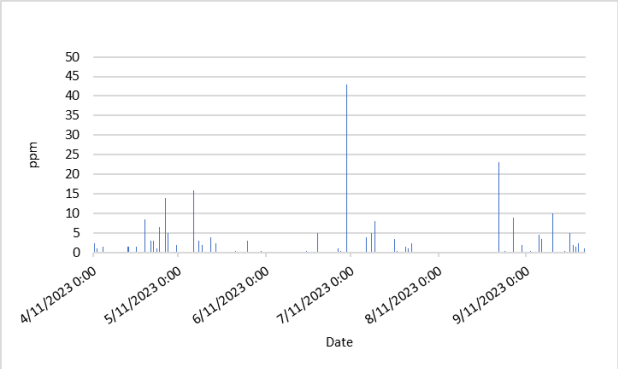

Figure 12. Concentration of CO at Perum Pemda Km. 10 Cilik Riwut

Peatland forest fires at Palangka Raya, Central Kalimantan in 2023 start in August with low to medium risk of hotspots (Figure 13). Hotspots are indicators of peatland forest fires in an area, so the more hotspots, the more potential for peatlands forest fires. If there is a peatlands forest fire in one location, it can be detected by satellite in one hotspot point, if two hot spot events that are still within a radius of 500 m can be detected only one hotspot, then a very large fire event can be detected 4 or more hotspots. This illustration illustrates that hotspot points are not the same as the number of peatlands forest fires in the field (Ginanjar, 2016). September – October hotspots are at a high level (Figure 14), the fire has spread everywhere and emits thick smoke covering Palangka Raya City.

Plants are air filters that are quite effective for cleaning the air and reducing pollution levels by absorbing, detoxifying, accumulating, and regulating metabolism in the air so that air quality is improved through the release of oxygen by plants (Shannigrahi, *et al*., 2015), pollutants are absorbed through leaf

biochemical processes, without showing damaging effects (Harris, *et al.*, 1999). Kusin, *et al.*, (2022b), studies in enclosed room filled with plants show very low concentrations of PM2.5 and CO compared to room without plants.

Figure 13. Hot spot at Palangka Raya City area on medium risk (https://hotspot.brin.go.id)

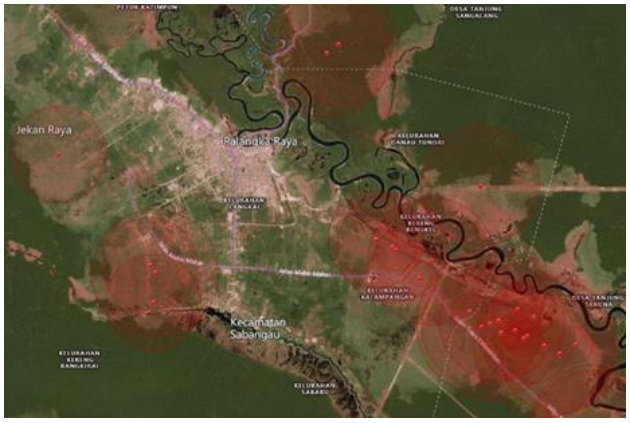

Figure 14. Hot spot at Palangka Raya City area on high risk (https://hotspot.brin.go.id)

The results of the researchers' findings, recorded from every peat forest fire tragedy in Sumatra and Kalimantan, are very high concentrations of PM2.5 and CO, also in this study. Smoke from peatland forest fires is the largest source of air pollution and its impact is harmful to human health and the environment. Continuous measurement of PM25 and CO concentrations, especially during the dry season when forest and peatland fires occur in affected areas and exposed to smoke from the fires. This measurement is carried out to determine the increase in PM2.5 and CO concentrations from normal to dangerous levels, so that measures can be quickly taken. It is necessary to find solutions and strategies, because peatland forest fires do not occur repeatedly, for example strengthening rules related to the prohibition of the use of forests and peatlands with a depth of >300m for agriculture/plantations or other activities, continuing to socialize by involving related stakeholders, social approach to the community, socializing agricultural land cultivation without burning, providing fertilizer subsidies for agriculture and no less important is provide jobs for the community. (Sutaata, *et al*., 2024), provides a solution by applying restorative justice for land and forest burners to provide a deterrent effect for perpetrators.

V. Conclusion

The results of the t-test on PM2.5 and CO concentrations in the rainy and dry seasons showed a p-value of < 0.05, meaning that there was a significant effect between the two seasons. During the peatland forest fire 2023, PM2.5 concentration reach to 700.24 $\mu g/m^3$, while the CO concentration is 7,446 $\mu g/m^3$ (6.5 ppm) at UPT LLG – CIMTROP and 333.39 $\mu g/m^3$ PM2.5 concentration, while the CO concentration is 26,439 $\mu g/m^3$ (23 ppm) at PERUM PEMDA Km 10 Cilik Riwut. Impact of peatland forest fires is very large for the environment and detrimental in terms of health, especially for babies, children's, pregnant mother, people with congenital diseases and the elderly. Together to find the best solution, so that peatland forest fires do not occur repeatedly. Socialization about the dangers of forest and land fires, especially related to harmful particles and gases contained from fire smoke and encouraging land clearing without burning must still be carried out.

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