Quantification methods of forest and land fires impact on the atmospheric environment (case study: oil palm plantation in Kayuagung District, OKI Regency, South Sumatra)

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Abstract. The impact of forest and land fires on the atmospheric environment can be classified into three components, namely ambient air quality, its contribution to greenhouse gases, and microclimate change. Each component has a different method for assessing and measuring the magnitude of its impact. The aim of the study is to obtain quantitative methods to assess the magnitude of the impact of forest and land fires on the atmospheric environment so that they can be used for the valuation of environmental losses. The magnitude of the impact of the air quality component is measured based on the Air Pollution Index (ISPU) and visibility, the component of the greenhouse gas is assessed by approaching the amount of GHG emissions and/or loss of carbon stocks, while changes in the microclimate by assessing changes in the level of thermal comfort. Gas and particulate emissions values of forest and land fires use the carbon mass balance approach and emission factors. Analysis of air pollution dispersion is conducted use the Gaussian model, with case study is the incidence of land fires in oil palm plantations located in Kayuagung sub-district, Ogan Komering Ilir Regency, South Sumatra Province in 2015, 2016 and 2017. The data used in this study consisted of Landsat 8 satellite imagery, MODIS and VIIRS Hotspots, measurements of vegetation biomass in the field, organic C-peat and climate data during fires. The results of the assessment show that land fires covering 551 ha in 2015, 59 ha in 2016 and 253 ha in 2018 have resulted in changes in the air pollutant standard index in Kayuagung from the medium category (ISPU PM10 = 75) to very unhealthy (ISPU PM10 = 272) in 2015, unhealthy (ISPU CO = 116) in 2016 and very unhealthy (ISPU CO = 205) in 2018. Visibility in an area of about 500-600 meters in the direction of the wind from the fire's location was less than 1 km with PM10 of more than 176 µg m⁻³. The contribution of GHGs to each fire's year is 26.8, 2.8 and 12.3 kilo tons of CO₂e consist of CO₂ and CH₄. The results of this study can be used to quantify the magnitude of the land fires impact on the atmospheric environment.

Keywords: atmosphere, air quality, Greenhouse Gas, land fires, impact magnitude

1. Introduction

Gas and particles emissions from land and forest fires into the atmosphere consist of water vapor (H₂O), permanent gases, volatile organic compounds, semi-volatile organic compounds, particles. In general, refers to the smoke produced by the fire as an aerosol which is defined as a colloidal system of solid or liquid particles dispersed in gases in the atmosphere [1]. The permanent gases consist of Carbon Dioxide (CO₂), Carbon Monoxide (CO) and Nitrogen Oxide (NOₓ). Sulfur oxides (SOₓ) and Ammonia (NH₃)
are also reported as permanent gases resulting from forest and land fires, although in low amounts [2-4]. Included in volatile organic compounds are methane (CH4) and some aliphatic and aromatic hydrocarbons such as alkanes and benzene and oxygenated hydrocarbon compounds such as alcohol [5-7]. Semi-volatile organics include polychromatic hydrocarbons such as benzo and pyrene. Emission of particulate matter (PM) resulting from fires released into the atmosphere according to their diameter consists of coarse particles or PM10 (more than 10 mm), fine particles or PM2.5 (more than 2.5 mm) and very fine (more than 0.1 mm) These particles can be organic and inorganic carbon, apart from direct combustion, PM carbon can also be formed from the sublimation of hydrocarbon gases.

Gases and PM emissions have an impact on changes in the composition of gases in the atmosphere, so that at certain limits causing the atmosphere to become polluted. This atmosphere pollution can cause (i) a decrease in atmosphere quality for the metabolism and health of living things, especially humans and (ii) a decrease in atmospheric visibility that can affect mobility and human activity. In addition to atmosphere pollution, emissions from land and forest fires also contribute to greenhouse gases (GHGs) which affect climate conditions on a local, regional and global scale. Each impact has different parameters and sizes, as well as the way it is assessed.

Approaches to identifying components of the affected atmosphere environment can use direct measurement methods and calculation models. The direct measurement method requires measurement instruments, for example to measure the ambient atmosphere gas content. Variants such as fuel, compound X emission factors and combustion efficiency according to the type of fuel can be calculated based on the results of measurements in the field when a fire occurs. The calculation model approach uses empirical values from several references, but still requires direct measurements in the field, especially those relating to the fuel source of a land fire event. The results of these two approaches can be used to compare the conditions of the atmosphere environment before and during the burnt.

The purpose of this study is to provide an alternative calculation of the impact of forest and land fires on the atmosphere environment by combining model approaches and field measurements. An example of the calculation is the fire incident at the location of the oil palm plantation located in Kayu Agung District, Ogan Komering Ilir Regency, South Sumatra. The geographical position of the fire location is at 03°20' - 03°30' South Latitude and 104°50' - 104°57' East Longitude, altitude is 10-15 meters sea above level. Fires occurred in 2015, 2016 and 2017 in different places at these locations (Figure 1)

![Figure 1](image-url)  
*Figure 1. The location of land fires 2015, 2016 and 2017 at Kayuagung District, Ogan Komering Ilir Regency, South Sumatera Province*
2. Stages and models of fire impact assessment

2.1 Stages of identifying variables and magnitude of impact

To understand methods for identifying the impact of forest and land fires on the atmosphere environment, the variables used to determine the components of these impacts must be known. The stage that can be taken to determine the impact of forest and land fires on the atmosphere environment was as follows in Figure 2.

![Diagram of fire impact assessment stages](image)

Figure 2. The identification stages of components of the impact of forest and land fires on the atmosphere environment

2.2 Carbon mass balance model

There are various approaches in calculating gas and particle emissions, i.e (i) by using the combustion factor (FP) and emission factor (EF) approaches of each gas and particle and (ii) the carbon mass balance approach that used by Seiler and Crutzen [8]. This study uses the calculation of gas and particle emissions with the carbon mass balance method. This approach is also used in the Ministry of Environmental Regulation No. 7/2014 that uses the emission ratio (ER) factor of gas compound X to CO2 gas. Emission calculations begin by calculating the burning material (tons) according to a burned area (ha), availability of fuel (tons/ha) and combustion factors (unit less) and converting them as carbon loss. The carbon fraction of the fuel is available using a single value, which is 0.45. Emission calculations use equations 1 and 2 by referring to the ER value for each gas (Table 1).

\[ B_t(C) = A \cdot F_c \cdot B_{t-1} \cdot FP \]  \hspace{1cm} (1)

\[ E_X = ER_X \times E_{CO2} \]  \hspace{1cm} (2)

Where \( B_t(C) \) is the result of carbon mass from biomass burned (tons), \( A \) is the area of burned (ha), \( F_c \) is the carbon fraction of biomass fuel (0.45), \( B_{t-1} \) is the fuel load (ton/ha) and FP is a combustion factor (Table 1). \( E_X \) is a gas or particle emission (X), \( ER_X \) is the emission ratio of gas X to CO2 and \( E_{CO2} \) is the CO2 gas emission. This calculation method uses the assumption used is 77% carbon is released as CO2. The conversion factor of C to CO2 is 3.67 (44/12). The value of \( ER_X \) for the gas is the same as
Levine and used by Hero [9] and used by Hero et al [10]. For peat soils, the Fc value uses the C-organic value resulting from laboratory analysis.

### Table 1. Combustion Factor by type of vegetation*)

| Vegetation types                  | Sub-vegetation types                               | Combustion Factor (%) |
|-----------------------------------|----------------------------------------------------|------------------------|
| Primary tropical forest           | Primary tropical forest                            | 0.32 ± 0.12            |
|                                  | Primary open tropical forest                        | 0.45 ± 0.09            |
|                                  | Wet tropical forest                                | 0.50 ± 0.03            |
|                                  | Dry tropical forest                                |                        |
|                                  | Average overall primary tropical forest            | 0.36 ± 0.13            |
| Secondary tropical forest        | Young regeneration forest (3-5 years)              | 0.46                   |
|                                  | Moderate secondary forest (6-15 years)             | 0.67 ± 0.21            |
|                                  | Old secondary forest (>15 year)                    | 0.50 ± 0.10            |
|                                  | Average overall secondary forest                  | 0.55 ± 0.06            |
| Bush and Shrubs                  |                                                     | 0.72 ± 0.25            |
| Savannah woodlands               |                                                     | 0.74 ± 0.14            |
| Savanna grassland                |                                                     | 0.77 ± 0.26            |
| Peatland                         |                                                     | 0.50                   |
| Tropical wetland                 |                                                     | 0.70                   |
| Agricultural                     |                                                     | 0.9 ± 0.1              |

*) IPCC (2006) [10]

### 2.3 Gas and particulate dispersion models

The burned area may occur more than one fire point. For example in an oil palm plantation concession, there were fires in several locations, so it was called multiple sources. This situation can be considered as a single source of emissions with the burned area as weighted factor [11]. Gases and PM emissions are expressed by per unit area and categorized as an area source or single polygon. The limitation used to refer to emission sources as area sources if the distance between the fire points is less than 100 m. If the distance between the fire points is more than 100 meters, referred to as a multiple point source. Quantification of emissions at multiple point sources is accumulated the amount each point source that received in the polluted area. The basic equation of the Gaussian model is as follows (equation 3):

\[
C(x, y, z, H) = \frac{Q}{2\pi \sigma_y \sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \left\{ \exp \left[ -\frac{1}{2} \left( \frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[ -\frac{1}{2} \left( \frac{z+H}{\sigma_z} \right)^2 \right] \right\}
\]

The variables C(x, y, z, H) are pollutant or gaseous particulate (g.m\(^{-3}\)) concentrations at points x, y, z and at the effective height H (m). Q is the rate of gas emission or particulate pollutants (g.s\(^{-1}\)). \(\sigma_y \sigma_z\) is the horizontal (y) and vertical (z) distribution constant or coefficient and is a function of distance (x). u is the average wind speed at the height of the pollutant source (m.s\(^{-1}\)), x is the horizontal puff distance from the pollutant source in the direction of the wind (m), y is the horizontal puff distance from the surface (m), H is the effective height (H = h + \(\Delta h\)), h is the height of the pollutant source (m). Estimated h values in forest and land fires can be estimated based on the height of the tree that matches the severity of the fire. The effective height (H) can also be approached by measuring the height of the smoke peak during a fire (\(\Delta h\)) or using the equation 4 as a function of surface wind speed [12].

\[
H = 28. v^{3/2}
\]

There can also use the buoyancy flux (Fb) approach according to the following equation (equations 5 and 6):

\[
H = h + \Delta h
\]

\[
\Delta h = \frac{16 Fb^{1/3} X^{2/3}}{u}
\]
Fb is the buoyancy flux (m$^4$s$^{-1}$), X is the distance of the midline when atmospheric turbulence begins to dominate the process of mixing atmosphere at the source (m), and u is the wind speed at the smoke height (m). The Fb value is obtained by the following equation 7, which is a specific function according to the type of gas.

$$Fb = \left(1 - \frac{\rho_x}{\rho}\right) \cdot g \cdot r_s^2 \cdot v_x$$

(7)

Where $\rho_x$ is the gas density $x$ (g.m$^{-3}$), $\rho$ is the density of atmosphere (g.m$^{-3}$), $g$ is the gravity of the earth (m.s$^{-2}$), $r_s$ is the radius of the pollutant source (m), and $v_x$ the speed of the pollutant at a vertical distance (m.s$^{-1}$). This Fb value can also be estimated based on the results of measurements of ambient atmosphere temperature (Ta-Kelvin) and the temperature of pollutant in the atmosphere (Ts-Kelvin) [13] (equation 8).

$$Fb = \frac{g \cdot v_x \cdot r_s^2 (Ts - Ta)}{4Ts}$$

(8)

The wind speed at the smoke level can be measured at the time of the fire or by using the wind speed measured at the surface of the local weather station during the fire ($u_0$), using the following equation (equation 9)

$$u = u_0 \left(\frac{Z}{Z_0}\right)^p$$

(9)

Where Z is the specific height when the wind speed value (u) to be determined, $Z_0$ is the measurement height $u_0$ and p is the coefficient value derived as a function of the atmosphere's stability class (Table 2) [14].

| Atmospheric stability class | P value for urban area | P value for rural area |
|-----------------------------|------------------------|------------------------|
| A                           | 0.11                   | 0.15                   |
| B                           | 0.12                   | 0.15                   |
| C                           | 0.12                   | 0.20                   |
| D                           | 0.27                   | 0.25                   |
| E                           | 0.29                   | 0.40                   |
| F                           | 0.45                   | 0.69                   |

The distance X in equation 8 can be measured during turbulence or atmosphere mixing occurs. Measurements in the field during a fire are rarely carried out, therefore it can use an empirical approach according to Fb and the understanding of smoke rising into the atmosphere will reach a certain level and become stable due to turbulence. The final height is formulated as follows (equation 10 and 11) [12]:

$$X = 49. Fb^{5/8}, Fb < 55 \text{ m}^4\text{s}^{-1}$$

$$X = 119. Fb^{2/5}, Fb > 55 \text{ m}^4\text{s}^{-1}$$

(10)

(11)

Horizontal ($\sigma_y$) and vertical ($\sigma_z$) dispersion coefficients are calculated using constants according to Pasquill-Gifford atmospheric stability conditions (Tables 3 and 4) and X (m) distances. The values of $\sigma_y$ and $\sigma_z$ can also be obtained from other equations such as Briggs, Carson and Moses, Holland models, Smith equation Momentum, Concawe and others [15], [16].
Table 3. Horizontal dispersion coefficient ($\sigma_y$) according to Pasquill-Gifford atmospheric stability class (Source: Visscher, 2014) [13]

| Atmospheric stability class | $\sigma_y$ urban area                     | $\sigma_y$ rural area                     |
|-----------------------------|-----------------------------------------|------------------------------------------|
| A                           | 0.32X (1+0.0004X)^{-1/2}                | 0.22X (1+0.0001X)^{-1/2}                |
| B                           | 0.32X (1+0.0004X)^{-1/2}                | 0.16X (1+0.0001X)^{-1/2}                |
| C                           | 0.22X (1+0.0004X)^{-1/2}                | 0.11X (1+0.0001X)^{-1/2}                |
| D                           | 0.16X (1+0.0004X)^{-1/2}                | 0.08X (1+0.0001X)^{-1/2}                |
| E                           | 0.11X (1+0.0004X)^{-1/2}                | 0.06X (1+0.0001X)^{-1/2}                |
| F                           | 0.11X (1+0.0004X)^{-1/2}                | 0.04X (1+0.0001X)^{-1/2}                |

Table 4. Vertical dispersion coefficient ($\sigma_z$) according to Pasquill-Gifford atmospheric stability class (Source: Visscher, 2014) [13]

| Atmospheric stability class | $\sigma_z$ urban area                     | $\sigma_z$ rural area                     |
|-----------------------------|-----------------------------------------|------------------------------------------|
| A                           | 0.24X (1+0.001X)^{-1/2}                | 0.20X                                    |
| B                           | 0.24X (1+0.001X)^{-1/2}                | 0.12X                                    |
| C                           | 0.20X                                  | 0.08X (1+0.0002X)^{-1/2}                |
| D                           | 0.14X (1+0.003X)^{-1/2}                | 0.06X (1+0.0015X)^{-1/2}                |
| E                           | 0.08X (1+0.015X)^{-1/2}                | 0.03X (1+0.0003X)^{-1/2}                |
| F                           | 0.08X (1+0.015X)^{-1/2}                | 0.0016X (1+0.0003X)^{-1/2}              |

Estimating the spread of pollutants with the Gaussian model can be used to assess the magnitude or contribution of land and forest fire emissions to pollution in certain areas. This model approach needs to be done because many fire cases do not take direct measurements at the time of the incident. Conversely, if in an area exposed to land fire pollutants there are atmosphere quality measurement instruments, then the measurement results can be used to validate the model. By testing the accuracy of the model results, the contribution of the burned area to atmosphere pollution can be calculated.

2.4. GHGs estimation

GHG emissions are estimated by two approaches, namely (i) quantifying the emissions of each GHG compound according to emission factors (EF), and (ii) according to emission ratios (ER). Both of them use the fuel load as the main variable, which consists of biomass, necromass and C-organic content of soil or peat. GHG emissions and/or carbon stock losses are calculated according to the burnt fuel load and then expressed as CO2e. The amount of burnt charge is obtained by comparing the amount before burning with the amount of non-burning. If biomass after fire is not measured, combustion factors can be used according to vegetation type. However, the use of this combustion factor will produce a conservative value and can only be used with the precautionary principle.

In the first approach, each GHG compound is calculated according to its emission factors, and then converted to CO2e by multiplying it by the GWP value, so the emission calculation equations are as follows:

$$E(CO_2e)_X = GWP_x \times (A.EF_X.B_{t-1}.EP.M_X)$$

$$E(CO_2e)_X = GWP_x \times (A.EF_X.B_{t-1}.FP.10^{-3})$$

$$E(CO_2e)_X = GWP_x \times (ER_X \times E_{CO_2})$$
The second approach is simpler than the first approach. The value of CO2e is directly calculated using the amount of carbon lost converted to a molecular weight ratio between CO2 and C (M_X). This means that all C released into the atmosphere is entirely considered GHG. The ratio of the amount of carbon stock in biomass (F_c) can use values that range between 0.45 - 0.5. In this paper, the calculation examples use the ratio value of 0.45 with the following equation (eq.15):

$$E(CO_2) = M_X \times B_t(C) \times 0.77 = M_X \times (A.F_c.B_{t-1}.FP) \times 0.77$$  \hspace{1cm} (eq. 15)

The assumption used is that 77% of carbon is released as CO2, and other types of GHG emissions are calculated with the ER value of CO2 with the following equation (eq.16)

$$E(CO_2e)_X = GWP_X \times ER_X \times E(CO_2)$$  \hspace{1cm} (16)

2.5. Variables and parameter
The implementation of the model above is used to determine the magnitude of the impact of fires in 2015, 2016 and 2018 on the atmosphere environment in Kayuagung and surrounding areas. The following are the variables and parameters used to calculate the impact of land fires on the atmosphere environment (Table 5).

**Table 5.** The variables and parameters of model to calculate gasses and PM emissions of land fire at the assessment site

| No | Variables and parameters | 2015 | 2016 | 2018 | Noted |
|---|--------------------------|------|------|------|-------|
| 1 | Burned area (ha)         | ±551 | ±59  | ±253 | Interpretation and digitization of Landsat 8 satellite imagery and field observations |
| 2 | Vegetation land cover class | Bush and shrub | | | Interpretation and digitization of Landsat 8 satellite imagery and field observations |
| 3 | Average biomass (tons/ha) | ±9.5 | ±9.5 | ±9.5 | Field measurement |
| 4 | Combustion factor of bush and shrub | | | | See Table 1 |
| 5 | Carbon fraction of biomass | 0.45 | | | Reference : IPCC (2006) |
| 6 | Burnt peat thickness (cm) | ±2 | ±2 | ±2 | Average of fuels measurement |
| 7 | C-organic of peat (%) | 0.5 | | | Average laboratory test result in unburned areas |
| 8 | Bulk density of peat (gr. cm^-3) | 0.22 | | | |
| 9 | Combustion factor of peat (unitless) | 0.5 | 0.5 | 0.5 | See Table 1 |
| 10 | Average wind speed | 16.7 | 6.9 | 7.5 | Local weather stations |
| 11 | Average wind direction | North-East | | | Local weather stations |
| 12 | Day of burned (day) | 9 | 2 | 5 | Interpretation of Hotspot (MODIS and VIIRS) |
| 13 | Average distance of closest settlement in the direction of the wind (km) | 8.5 | 11.5 | 8.5 | Estimation of burn location to closest settlement |
| 14 | Air Pollution Index (ISPU) before the fire at Kayuagung | 75 | | | Assumption for the normal condition (See Table 5) |
| 15 | Solar radiation (watt.m^-2) | 300-600 | | | it is assumed to be clear weather at night |

Gas and PM pollutant is calculated based on the assumption that normal conditions have moderate atmosphere quality and no dominant elements. Air Pollution Index (ISPU) value is 75. The amount of gases and PM pollutant under these conditions is calculated by the following equation 12:

$$l = \frac{Ia-Ib}{Xa-Xb} (Xa - Xb) + Ib$$  \hspace{1cm} (eq. 17)
Where, $I = \text{ISPU}$ is calculated; $I_a = \text{ISPU upper limit}$; $I_b = \text{ISPU lower limit}$; $X_a = \text{upper limit ambient}$; $X_b = \text{lower boundary ambient}$; $X_x = \text{real ambient content measured or calculated}$. Based on assumptions and equation 12, the ambient content for each gas and pollutant particles in the initial conditions (no fire) is as follows (Table 6):

**Table 6.** The ambient level of gas and PM pollutant before fire occurrence at Kayuagung (assuming the ISPU value is moderate)

| ISPU | 24 hour PM | 24 hour $\text{SO}_2$ | 8 hour $\text{CO}$ | 1 hour $\text{O}_3$ | 1 hour $\text{NO}_2$ |
|------|------------|------------------------|-------------------|-------------------|---------------------|
| 75   | 100        | 222.5                  | 7.5               | 177.5             | 2                   |

3. **Magnitude of impact on the atmosphere environment**

3.1. *The magnitude of gas and particulate emission*

The mass of gas and particulate emissions from fires in 2015, 2016 and 2018 in the study area is proportional to the area and number of fire days. The burned peat layer produced a greater contribution compared to the burned biomass (Table 7, 8 and 9).

**Table 7.** The gases and particulate emissions of fires occurrence 2015 in the study area

| Gasses and PM | Emission (ton) |  |
|---------------|--------|---|
|               | Biomass | Peat | Total (ton) |
| CO2           | 4792.7  | 17127.8 | 21920.4      |
| CO            | 407.4   | 3168.6  | 3576.0        |
| CH4           | 15.3    | 178.1   | 193.5         |
| NOx           | 10.1    | 78.8    | 88.9          |
| O3            | 23.0    | 178.1   | 201.1         |
| NH3           | 4.3     | 219.2   | 223.5         |
| PM            | 104.7   | 233772.8 | 233877.5     |

**Table 8.** The gases and particulate emissions of fires occurrence 2016 in the study area

| Gasses and PM | Emission (ton) |  |
|---------------|--------|---|
|               | Biomass | Peat | Total (ton) |
| CO2           | 513.2   | 1834.0  | 2347.2       |
| CO            | 43.6    | 339.3   | 382.9        |
| CH4           | 1.6     | 19.1    | 20.7         |
| NOx           | 1.1     | 8.4     | 9.5          |
| O3            | 2.5     | 19.1    | 21.5         |
| NH3           | 0.5     | 23.5    | 23.9         |
| PM            | 11.2    | 2680.4  | 2691.6       |

**Table 9.** The gases and particulate emissions of fires occurrence 2018 in the study area

| Gasses and PM | Emission (ton) |  |
|---------------|--------|---|
|               | Biomass | Peat | Total (ton) |
| CO2           | 2200.6  | 7864.5  | 10065.1     |
| CO            | 187.1   | 1454.9  | 1642.0      |
| CH4           | 7.0     | 81.8    | 88.8        |
| NOx           | 4.6     | 36.2    | 40.8        |
| O3            | 10.6    | 81.8    | 92.4        |
| NH3           | 2.0     | 100.7   | 102.6       |
| PM            | 48.1    | 49286.9 | 49335.0     |
3.2. Atmospheric pollution in Kayuagung

In this study, not all gases resulting from land fire emissions are polluting. Atmospheric pollutant gases from land fires include CO, O₃, NOₓ and particles (PM). Model results prove that all 2015, 2016 and 2018 fire incidents contributed to the ambient levels of pollutant gases in the receiving area (Kayuagung) according to the emission load and distance (Table 10 and Appendix 1).

Table 10. The levels of ambient gas and PM pollutant during a fire in Kayu Agung (assuming the initial ISPU value is moderate = 75)

| Year | Initial ambient levels (mg/m³) (ISPU = 75) | Fires Contributions (mg/m³) | Final ambient level/during fire event (mg/m³) |
|------|------------------------------------------|-----------------------------|---------------------------------------------|
|      | 24 hours PM | 24 hours SO₂ | 8 hours CO | 1 hours O₃ | 1 hours NO₂ | 2015 | n/d | 4.6 | 0.3 | 0.1 |
| 2015 | 100 | 222.5 | 7.5 | 177.5 |          | 500.1 | n/d | 4.6 | 0.3 | 0.1 |
| 2016 | 100 | 222.5 | 7.5 | 177.5 |          | 25.5 | n/d | 3.6 | 0.2 | 0.1 |
| 2018 | 100 | 222.5 | 7.5 | 177.5 |          | 253.8 | n/d | 8.4 | 0.5 | 0.2 |

| Year | 24 hour PM | 24 hour SO₂ | 8 hour CO | 1 hour O₃ | 1 hour NO₂ | 2015 | n/d | 12.1 | 177.8 | 2.1 |
|------|------------|-------------|-----------|-----------|------------|------|-----|-------|--------|------|
| 2015 | 272 | n/d | 130 | 75 | n/d | 400.1 | n/d | 12.1 | 177.8 | 2.1 |
| 2016 | 88 | n/d | 116 | 75 | n/d | 125.5 | n/d | 11.1 | 177.7 | 2.1 |
| 2018 | 205 | n/d | 185 | 75 | n/d | 353.8 | n/d | 15.9 | 178.0 | 2.2 |

The increasing pollutant load has caused changes in the atmospheric pollution index calculated based on regulation no.107 / BAPEDAL / 11/1997 on technical guidelines for calculation and reporting as well as atmospheric pollutant index information (Table 11). Based on the guidelines, the highest ISPU value is used as an indication of atmospheric pollution. Thus, the ISPU in 2015 fires was 272 with the dominant pollutant being PM, in 2016 ISPU was 116 with the dominant pollutant being CO gas and the ISPU in 2018 was 205 with the dominant pollutant being the PM. The consequence of this ISPU value is that the atmospheric environment in 2015 is categorized as "very unhealthy", 2016 is "unhealthy" and in 2018 is "very unhealthy" (Table 12).

Table 11. The ISPU values in the recipient area (Kayuagung) due to land fires in the study area

| Year | 24 hour PM | 24 hour SO₂ | 8 hour CO | 1 hour O₃ | 1 hour NO₂ |
|------|------------|-------------|-----------|-----------|------------|
| 2015 | 272 | n/d | 130 | 75 | n/d |
| 2016 | 88 | n/d | 116 | 75 | n/d |
| 2018 | 205 | n/d | 185 | 75 | n/d |

| Year event | ISPU | Impact | Categories based on highest ISPU of pollutant |
|------------|------|--------|---------------------------------------------|
| 2015 | ISPU PM (272) | Visibility drops and increased sensitivity of patients with asthma and bronchitis | very unhealthy |
|        | ISPU CO (130) | Cardiovascular increase in people with heart disease |
|        | ISPU O₃ (75) | Wounds on several types of plants |
| 2016 | ISPU CO (116) | Cardiovascular increase in people with heart disease | unhealthy |
|        | ISPU PM (88) | There was a decrease in visibility |
|        | ISPU O₃ (75) | Wounds on several types of plants |
Visibility drops and increased sensitivity of patients with asthma and bronchitis
Cardiovascular increase in people with heart disease
Wounds on several types of plants

Atmospheric quality pollution has also affected visibility. Based on the distance from the location of the fire, areas in the direction of the wind that have PM levels of more than 176 µg / m³ are included in the unhealthy category, especially in 2015 and 2018. Visibility in areas that are around 500-600 meters from the location fire is less than 1 km. This means, if there is an airport in the area, then all flights will be canceled (see Table 13 and Appendix 1).

### Table 13. The empirical relationships between pollutant particle load, visibility and Atmospheric quality

| PM<sub>2.5</sub>-PM<sub>10</sub> (µg.m<sup>-3</sup>) | Visibility (km) | The soundness or air quality | Community activities guide |
|------------------------------------------|-----------------|------------------------------|----------------------------|
| Average of 1-3 hour | Visibility (km) |                              |                            |
| 0-40 | >15 | Good | • Ideal Atmospheric quality for outdoor activities |
| 41-175 | 5-14 | Moderate | • Be aware of the health effects of smoke and related symptoms.  
• For certain groups *) reduce or reschedule prolonged strenuous activities and limit the time spent outdoors. |
| 176-300 | 2.5-4 | Unhealthy for certain groups *) | • Reduce or reschedule prolonged heavy activity outdoors, especially if you experience symptoms.  
• For certain groups *) avoid prolonged strenuous activities and stay indoors if possible. |
| 301-500 | 1.5-2.5 | Unhealthy | • Avoid prolonged strenuous activities and stay indoors if possible.  
• For certain groups *) avoid all strenuous activities and stay indoors if possible. |
| >500 | <1 km | Very Unhealthy (Hazardous) | Avoid all strenuous activities and stay indoors. |

*) The most common categories of people at high risk are problematic respiratory and cardiovascular conditions, young children, pregnant women and the elderly.

### 3.3. GHG Contributions

Forest and land fires in Indonesia are mentioned as one of the major contributors to GHG emissions, especially in forests and peatlands. Hooijer et al reported CO2 emissions ranging from 3.0-9.4 Gt or around 40% of global emissions as a result of peatland fires in 1997, 1998 and 2002 in Kalimantan and Sumatra, with fires ranging between 1.5-2.2 million ha annually [18]. The 2006 fires resulted in emissions of 0.098 ± 0.180 Gt CO₂ from 2.79 million ha of forests and peatlands [19]. The mapping of satellite imagery by GFED v.4 (2019) shows that land and forest fires in Indonesia in 2015 contributed around 1.75 Gt CO₂ to global emissions. The overall estimated value of the emissions shows that the largest emissions are generated from fires on peatlands. CO₂ emissions from peatland fires cannot be combated or replaced with the regrowth of plants above them, because fires have burned carbon stored for thousands of years. Referring to the explanations above, then in the case of forest and land fires, the GHG component is assessed based on the amount of gas released into the atmosphere.

In this study, the calculation of GHG emissions uses the approach of calculating the amount of emissions for each GHG (CO₂, CH₄ and N₂O) in the previous section, then the CO₂e equivalent value is calculated according to its GWP. The carbon mass balance approach does not produce emissions of N₂O compounds, therefore, the amount of GHG is only the sum of CO₂ and CH₄ gas compounds. Table 14
shows the amount of CO\textsubscript{2}e that can be used to calculate losses from land fires due to contributing to climate change.

### Table 14. Contribution of land fires in the study area to GHG in the atmosphere

| Year | GHG  | GWP | Mass of Emission (ton) | CO2e (ton) | Total CO2e (ton) |
|------|------|-----|------------------------|------------|-----------------|
| 2015 | CO2  | 1   | 21920.4                | 21920.4    | 26757.9         |
|      | CH4  | 25  | 193.5                  | 4837.5     |                 |
| 2016 | CO2  | 1   | 2347.2                 | 2347.2     | 2864.7          |
|      | CH4  | 25  | 20.7                   | 517.5      |                 |
| 2018 | CO2  | 1   | 10065.1                | 10065.1    | 12285.1         |
|      | CH4  | 25  | 88.8                   | 2220       |                 |
|      |      |     |                        |            | **Total CO2e (ton) 41907.7** |

### 4. Conclusion

The results of the assessment show that land fires covering 551 ha in 2015, 59 ha in 2016 and 253 ha in 2018 have resulted in changes in the atmospheric pollutant standard index in Kayuagung from the medium category (ISPU PM10 = 75) to very unhealthy (ISPU PM10 = 272) in 2015, unhealthy (ISPU CO = 116) in 2016 and very unhealthy (ISPU CO = 205) in 2018. Visibility in an area of about 500-600 meters in the direction of the wind from the fire's location was less than 1 km with PM10 of more than 176 µg m\textsuperscript{-3}. The contribution of GHGs to each fire's year is 26.8, 2.8 and 12.3 kilo tons of CO\textsubscript{2}e consist of CO\textsubscript{2} and CH\textsubscript{4}.

The impact of forest and land fires on the atmospheric environment can be quantified by a model approach and field measurements. The impact is atmosphere quality pollution and contribution to GHG in the atmosphere. The emissions and dispersion models used in this study still require input data from field measurement. Important data should be taken by field measurement are burned area, fuel load, weather observation and data related to population. This model can be considered as a reference for the impact or losses valuation of land and forest fires.

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