Chemical Composition of Fine Particulate Matter from Peat Forest Fires at Palangka Raya and Its Dispersion using HYSPLIT

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Abstract. An air quality monitoring was conducted to investigate the chemical characteristics of particulate emissions in peat forest fires at Palangka Raya, Indonesia during 2012 where a peat forest fire episode occurred. Aerosol samples were collected at Palangka Raya where represents a sub urban site downwind of the peat forest fires. The samples were collected using Gent stacked filter unit sampler. The sampler provides two size fractions: coarse (2.5-10 μm equivalent aerodynamic diameters EAD) and fine (<2.5 μm EAD). Black carbon (BC) was measured using Smoke Stain Reflectometer, and elemental compositions were analyzed using X-ray Fluorescence (XRF). The concentrations of PM₂.⁵ during a haze episode were significantly different about seven to eight times higher when compared to the concentrations in non-haze conditions. The major components of PM₂.⁵ in peat smoke haze consist of sulphur, biomass burning component (BC, K), and crustal components (Al, Fe, Si). The sulphur mainly comes from the peat as it is the earliest stage of transition from compressed plant growth to the formation of coal. The dispersion pattern to show the effect of wind direction using the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) simulation was also applied.

Keywords : particulate, emissions, peat, forest fires.

1. Introduction
In Indonesia, forest fires from uncontrolled burning of large areas of lands are major problem for air quality. Tropical peat/forest fires in Indonesia are generally caused by illegal human activities including land clearing, converting to agricultural lands through heavy logging and slash and burn techniques, use of fire as weapon in land tenure/disputes, fire for resource extraction and accidental fire [1]. Usually the fires take place in the dry season in September-November. Most of these fires particularly occur in Kalimantan and Sumatra islands, which have the world largest areas of tropical peat lands. Indonesia has approximately 83% (225,000 km²) of peat land in Southeast Asia of which 26% and 13% are in Kalimantan and Central Kalimantan respectively. A large Mega Rice Project (MRP) was carried out near Palangka Raya, Central Kalimantan. The MRP area consists of 9191 km² peat swamps. This kind of large-scale land development resulted in extensive deforestation. MRP peat with roughly 4500 km² is more than 3 m depth and is the main source of fire-related air pollution [2].

During the haze episode, several studies of the chemical composition of the fire aerosol have been performed at Palangka Raya, Central Kalimantan. Most of them focus on TSP and PM10, organics components and some on inorganic material. Study related to peat fires in 1997 reported during peat...
fires that total suspended particulate (TSP) were detected more than 4000 ug/m3 exceeding the Indonesian national air quality standard by a factor of 15 [3]. In particular, peat fires could become an even worse air pollution source due to its underground fires and also its impact to other regions nearby as trans-boundary haze pollution. Neighbouring country such as Malaysia and Singapore experienced severe air pollution exceeding the typical air quality standards due to the peat fires in Kalimantan [4], and the impact of it also appeared in Brunei and even Southern Thailand [5]. In order to reduce trans-boundary haze pollution from vegetation fires, information on pollution sources and their impacts need a thorough investigation. For urban air pollution sources, there are several reports in Indonesia, but only a few for peat fires [6, 7]. Studies about fine particulate (PM$_{2.5}$) and its chemical composition are still lack.

Several epidemiological studies conducted in different parts of the world indicate that there are strong correlations between exposure to airborne particulate matter and increased morbidity and mortality [8]. Moreover, PM$_{2.5}$ emitted from biomass burning is a major contributor for bronchial-related problems [9]. The content of some metals in aerosols, when deposited in the lower airways, can lead to acute and chronic effects on the lung [10]. Therefore, the monitoring and assessment of the impact of forest fires on air quality is required especially on its content of certain elemental concentration.

In this study, the observation of air quality during peat fires episode in Palangka Raya is discussed which focused on the fine particulate to investigate the chemical characteristics of particulate emissions in peat fires and its dispersion to show the effect of the wind that travel through transboundary and influence to the neighbouring countries.

![Figure 1. Sampling site in Palangka Raya, Kalimantan](image)

2. Materials and methods

2.1. Sampling

Samplings were carried out in Palangka Raya, Kalimantan (Borneo). Palangka Raya is the capital city of Central Kalimantan Province, has the area width around 2678.51 km$^2$. Palangkaraya is located at 75 metres above sea level. In general, Palangka Raya has two seasons, dry season (June to October) and wet season (November to March). Palangka Raya population in the year of 2011 are recorded 224663 based on population census 2010 (Palangka Raya City in Figures, 2011). The sampling site is located on 113° 52'49" E and 02°10'30" S. Samples were collected in January – December 2012 using a Gent stacked filter unit sampler provided by International Atomic Energy Agency that is capable for collecting particulate matter in the PM$_{2.5-10}$ (coarse) fraction and PM$_{2.5}$ size (fine) fraction [11]. The coarse fraction PM$_{2.5-10}$ samples were collected on 8.0 μm nuclepore filters, whereas the fine fraction PM$_{2.5}$ samples were collected on 0.4 μm nuclepore filters. Sampling was performed at a flow rate of 15-18 L.min$^{-1}$ for 24 hours with a frequency of once a week. Sampler was placed on the rooftop of a container 2-3 m above ground level and the intake nozzle of the sampler is located 1.8 m above the roof. The total of 51 pairs of PM$_{2.5}$ and PM$_{2.5-10}$ samples were collected from this site.
2.2. Mass concentrations, black carbon and elemental analysis

The particulate matter mass of each fine and coarse fractions were determined by gravimetric using a six digits microbalance. The filters were stored for 24 hours prior to weighing in controlled environmental condition room. Mass concentrations of PM$_{2.5}$ and PM$_{2.5-10}$ ($\mu$g.m$^{-3}$) were obtained by dividing the gravimetric mass by the volume of air that passed through the filter. The concentration of black carbon (BC) in the samples was determined by reflectance measurement using a Smoke Stain Reflectometer model 43D. Secondary standard of known reflectance was used to calibrate the reflectometer. The elemental composition analysis was conducted using Epsilon 5 EDXRF spectrometer from Panalytical, which has a 100kV excitation source and a polarising optical path give detection limits in the low ng/cm$^2$ range for most elements. The calibration was set up using macromatter standard, reference material and a blank standard for each element, Mg, Al, Si, S, K, Ca, Ti, Mn, Fe, Ni, Zn and Pb. The method validation of this application was applied by analyzing the standard reference material air dust on air filter SRM NIST 2783.

3. Results and Discussions

3.1. Particulate matter concentrations

Fine and coarse fraction concentrations were resumed in Table 1. Twenty four hours fine fraction PM$_{2.5}$ concentration ranged from 1.64 to 55.73 $\mu$g m$^{-3}$ with average value of 12.54 $\mu$g m$^{-3}$, and for coarse fraction mass concentrations ranged from 3.69 to 80.67 $\mu$g m$^{-3}$ with average value of 14.88 $\mu$g m$^{-3}$, while the PM$_{10}$ concentration ranged from 7.94 to 136.4 $\mu$g m$^{-3}$. Time series of PM$_{2.5}$ and PM$_{10}$ concentrations is shown in Figure 2.

| Parameter                | Sampling site, Palangka Raya |
|--------------------------|------------------------------|
|                          | Fine Fraction ($\mu$g m$^{-3}$) | Coarse Fraction ($\mu$g m$^{-3}$) |
| Average                  | 12.54                        | 14.88                          |
| Median                   | 7.75                         | 10.96                          |
| Standard deviation       | 12.54                        | 14.08                          |
| Minimum                  | 1.64                         | 3.69                           |
| Maximum                  | 55.73                        | 80.67                          |

Even none of the annual average and the twenty four hour of PM$_{2.5}$ and PM$_{10}$ concentrations exceed the Indonesian National Ambient Air Quality Standard NAAQS (15, 65 and 150 $\mu$g m$^{-3}$ respectively), but there were periods in September – October 2012 that high concentrations were 7-8 times higher than concentrations in other periods observed. These periods have been identified that the peat forest fires occurred. LAPAN National Institute of Aeronautics and Space reported that more than hundreds hotspot were observed in Kalimantan on 15 and 19 September 2012.

3.2. Black carbon and elemental concentrations

Black carbon concentrations in PM$_{2.5}$ time series is shown in Figure 3. The BC concentrations ranged from 0.19 to 3.08 $\mu$g m$^{-3}$, with average 1.37 $\mu$g m$^{-3}$. The average percentage ratio of BC in PM$_{2.5}$ was 16%. The BC concentration did not show high peak and any fluctuation as shown in PM$_{2.5}$ and PM$_{10}$ concentration on September-October 2012, when the period of peat forest fires occurred. The BC concentrations in this period are 2-3 times higher than other periods, even though the magnitude is not high as the increasing of the mass concentration, it seems that the forest fires episodes contribute to the increasing of BC concentrations in this period. The peat forest fires are substantial sources of BC, as well as biomass burning since the peat forest fires burn through thick layers of peat (dead plant
debris/biomass) that blanket the ground in ecosystems [12, 13]. Besides BC, the increasing of amount of several elemental concentrations also contributes to the increasing of the mass, as well as other organic compounds [13].

\[\text{Figure 2. Time series of PM} \_\text{2.5 and PM} \_\text{10 concentrations}\]

\[\text{Figure 3. Time series of BC concentrations in PM} \_\text{2.5}\]

Table 2. Elemental concentrations in fine fraction (ng/m3) in 2012 period at Palangka Raya

| Element | Mean | Range |
|---------|------|-------|
| Mg      | 32.7 | 1.2 - 79.3 |
| Al      | 147  | 110 - 252 |
| Si      | 72.5 | 19.4 - 175 |
| S       | 400  | 40.3 - 1757 |
| K       | 107.7| 4.17 - 357 |
| Ca      | 24.1 | 5.76 - 52.5 |
| Ti      | 5.84 | 2.20 - 15.1 |
| Mn      | 2.94 | 1.15 - 6.01 |
| Fe      | 207  | 168 - 381 |
| Ni      | 1.35 | 0.51 - 3.44 |
| Zn      | 6.79 | 3.45 - 18.34 |
| Pb      | 2.28 | 0.15 - 6.04 |
Elements such as Mg, Al, Si, S, K, Ca, Ti, Mn, Fe, Ni, and Zn were detected in the most of samples. The concentrations of elements were resumed in Table 2. The elemental concentrations in PM$_{2.5}$ in Palangka Raya sampling site are shown as box and whisker plot in Figure 4. The box represents 25% to 75% of the distributions of the concentration. The box represents 25% to 75% of the value. The horizontal bar in the box indicates that the median and the plus symbol (+) denotes the mean data. The points lying outside the range defined by the whiskers are plotted as outlier dots. It can be seen that high concentrations of S, K, and crustal elements Al, Si, Fe were identified. The time spatial distribution of S and K showed that the high concentrations of S and K were observed in the period of September – October 2012 when peat forest fires were occurred (Figure 5 and Figure 6). Peat is the earliest stage of transition from compressed plant growth to the formation of coal [14], therefore a lot of sulphur contained in the peat and it released some amounts of sulphur emission due to the burning [15]. Although the types of plants and combustion conditions may influence the composition of particles emitted to the atmosphere, but Ikegami has reported on forest fires at Kalimantan in 1997 that high accumulation of sulphur in particles in the atmosphere after their emission was not in the form of sulfuric acid since ammonia would be generated from biomass burning and would neutralize sulfuric acid [16]. Okada et al (2001) found that the haze particles over Kalimantan were identified as ammonium sulphate [17]. Beside sulphur, other key elements associated with biomass burning was found in high concentration was potassium. Potassium is one of the key elements of biomass burning [12, 18].

![Figure 4. Elemental concentrations in PM$_{2.5}$](image1)

![Figure 5. Box and whisker plot of S concentrations in PM$_{2.5}$](image2)

3.3. Particulate Dispersion

In 2012 peat forest fire period, the dispersion pattern to show the effect of wind direction using the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) simulation were applied. The result is shown in Fig. 7. The dispersion distribution showed that the particulate matter from this
area was not able to reach the other regions, which within 48 hours the concentration of particulate was found to reduce as it dispersed in the surrounding area. It indicated that distribution of particulate matter in the surrounding areas was not influenced by the wind direction and can be concluded that the peat forest period occurred in 2012 at Palangka Raya did not influence the other countries nearby since it has been dispersed before traveling trans-boundary. This fact could present information about public concern since Indonesian has been accused for several peat forest fires due to the haze.

Figure 6. Box and Whisker plot of K concentrations in PM$_{2.5}$

Figure 7. The dispersion distribution of particulate matter within 48 hours on Sept 15, 2012
Haze is problematic for several reasons as it indicates significant forest fire could release big amount of emissions, affects economic activities, tourism, and threatens diplomatic relation between neighbouring countries [19]. Some facts were also revealed that haze was identified as major problem in 1997 and was exacerbated by unusually long droughts connected to El Nino, and it has returned in years unaffected by El Nino, most seriously in 2005, 2006 and 2013. In 2013, it was found from several local newspapers that the haze has been affected Singapore badly [19]. Further study is needed in order to clarify the case of the peat forest fires in 2013 which affected Singapore, through applying the similar approach in this study.

4. Conclusions
The chemical characteristic of particulate emission of peat forest fire in 2012 at Palangka Raya on Central Kalimantan, Indonesia was investigated. The mass concentration during the peat forest fires was 7-8 times higher than normal condition. The high concentration of S, BC and K which associated with the biomass burning was identified. Peat is the earliest stage of transition from compressed plant growth to the formation of coal which contains large amount of sulphur. Further analysis of organic compound should be conducted in the samples to ensure the consistency the form of sulphur and carcinogen elements in the samples. It was also found that the peat fires happened in the period did not affect to other neighbouring countries like happened in 1997, 2005, and 2006.

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