



A Case Study of PM_{2.5} Characterization in Bangi, Selangor, Malaysia during the Southwest Monsoon Season

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ABSTRACT

A case study was carried out to characterize the ambient PM_{2.5} based on ground-based sampling in Bangi, Selangor, Malaysia in September, 2013 during the southwest monsoon season. We determined the total mass concentration, organic carbon, elemental carbon (EC), and metals in PM_{2.5} samples. The mean PM_{2.5} mass concentration was 44.5 μg m⁻³, showing that it exceeded the national air quality standard of 35 μg m⁻³ for 24-hour PM_{2.5} by the U.S. Environmental Protection Agency. Relatively high OC and EC concentrations of this study compared to those of other Southeast Asian countries were observed, which indicate that significant sources of OC and EC exist. The results of char-EC/soot-EC ratios strongly suggest that biomass burning is the main contributor to ambient EC concentrations compared to coal combustion and motor vehicle emissions. From calculations using the mass closure model, organic matter was the most abundant component in PM_{2.5} mass at 22.4 ± 6.65 μg m⁻³, followed by nss-sulfate at 4.84 ± 2.49 μg m⁻³, and EC at 4.11 ± 0.916 μg m⁻³. This result indicates that targeting the sources of carbonaceous PM_{2.5} is a crucial step to improve the air quality in this study field.

Keywords: PM_{2.5}; OC; EC; Malaysia.

INTRODUCTION

Particulate matter (PM) is a major cause of air pollution, originating from various sources in Southeast Asia such as biomass burning, industry, automobiles, and domestic cooking. Expansion of domestic and international demand for agricultural products such as palm oil, sugar cane, and rice, accelerates deforestation and biomass burning in Southeast Asia (Reid *et al.*, 2013). In Southeast Asia, it is estimated that an average of 330 Tg of biomass is annually burned (Streets *et al.*, 2003). Then, biomass burning has further reduced air quality in this region.

Malaysia is one of the countries that has PM pollution from many sources such as vehicle and industrial emissions, and Indonesian peatland fire during the southwest monsoon (dry) season from June to October (Fujii *et al.*, 2014a, 2015).

Since the Recommended Malaysian Ambient Air Quality Standards (RMAAQS) of PM have been established for particulate matter with diameters ≤ 10 μm (PM₁₀), total suspended particles, and lead (Pb), many reports have presented data regarding these forms of PM (Abas and Simoneit, 1996; Fang *et al.*, 1999; Okuda *et al.*, 2002; Abas *et al.*, 2004a, b; Omar *et al.*, 2007; Norela *et al.*, 2013; Wahid *et al.*, 2013; Jamhari *et al.*, 2014). Particulate matter with diameters ≤ 2.5 μm (PM_{2.5}) has a higher health risk than PM₁₀ due to its ability to penetrate deep into the respiratory tract, longer transport distance and longer residence time in the atmosphere. Unfortunately, RMAAQS for PM_{2.5} are not established and chemical characterization of ambient PM_{2.5} is necessary for evaluating human health effects and source apportionment. Recently, PM_{2.5} concentrations have been reported (Tahir *et al.*, 2013; Fujii *et al.*, 2014b; E-Ling *et al.*, 2015; Khan *et al.*, 2015), however, the identified components are limited such as inorganic ions and metals.

Large biomass burning, particularly from transboundary sources (Mahmud 2009), is expected to be a major source contribution to ambient PM_{2.5} in Malaysia. Carbonaceous components are dominant species in biomass burning aerosol

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(Reid *et al.*, 2005). Therefore, carbonaceous species in PM_{2.5} is indispensable to the source apportionment and evaluation of human health effect of PM_{2.5}, but there is little data on carbonaceous PM_{2.5} in Malaysia. Then, we aimed to specify the chemical composition of ambient PM_{2.5} for source identification during the southwest monsoon season when transboundary haze from Indonesian peatland fire is often observed in Malaysia. As a first step, we have determined carbonaceous and metal components of PM_{2.5} with intensive samplings during the southwest monsoon season to provide information required for source identification.

METHODS

Sampling Site

The sampling site was Universiti Kebangsaan Malaysia (UKM) located in Bangi, Selangor, Malaysia. A detailed description of the sampling site has been provided in our former report (Fujii *et al.*, 2014b). PM_{2.5} samples were collected on the roof in UKM (~22 m above ground level, Latitude, Longitude: 2°55'41"N, 101°46'47"E) from September 16 to 25, 2013 (sampling number = 8). The average daily ambient temperature and relative humidity during the sampling period obtained from the UKM weather station (~1 km away from the sampling site) were 27.5°C and 87.7%, respectively.

Bangi (89 m above sea level) is located ~25 km south from Kuala Lumpur and ~35 km from the Malacca Strait. The development of the administrative area of Putrajaya, educational centers and several small-medium industrial areas around Bangi have led to a large increase in the volume of traffic around Bangi (Wahid *et al.*, 2013). Industrial areas within 100 km from Bangi defined by the Department of Environment are Petaling Jaya (~30 km northwest), Nilai (~35 km south), and Bukit Rambai (~100 km southeast). Because September is the southwest monsoon season in Malaysia, PM in Bangi may be affected by industry sources in Nilai and Bukit Rambai as well as Indonesian peatland fires.

Sample Collection and Analysis

Two sets of PM_{2.5} samplers (ChemComb model 3500 speciation sampling cartridge, Thermo) equipped with volatile organic compound denuders to reduce artifacts of organic gases were utilized to continuously collect PM_{2.5} on 47 mm polytetrafluoroethylene (PTFE) and quartz fiber filters for 24 hours (starting time was approximately 07:10 local time) at a flow rate of 10 L min⁻¹. After sampling, we determined the total mass concentration, organic carbon (OC), elemental carbon (EC), and metals in the PM_{2.5} samples.

The PTFE filter was weighed on an electronic microbalance (ME5-F, Sartorius) with a sensitivity of ±1 µg in a stable environment of 23.8 ± 1.0°C (average ± standard deviation) and 33.8 ± 0.8 RH% (RH: relative humidity) before and after sampling to determine PM_{2.5} mass concentrations.

The carbonaceous contents of the aerosols were quantified using a DRI Model 2001 OC/EC Carbon Analyzer, which employs the thermal optical reflectance method using the IMPROVE_A protocol. A detailed description of the

quantification procedure, method detection limit (MDL), precision, and accuracy have been provided elsewhere (DRI, 2005). Additionally, the OC and EC contents [µg cm⁻²] on the collected filters for our samples were approximately 30 and 80 times higher than those for MDL determined by DRI (2005), respectively.

Metals were analyzed using an energy-dispersive X-ray fluorescence spectrometer (EDXL300, Rigaku). In this study, eight metals (Al, Si, K, Ca, Ti, Fe, Zn, and Pb) were quantified. A detailed description of the quantification procedure, MDL, precision, and accuracy have been provided elsewhere (Okuda *et al.*, 2013, 2014).

RESULTS AND DISCUSSION

PM_{2.5} Mass and Chemical Species Concentrations

The daily PM_{2.5} mass concentration during the sampling period was 44.5 ± 8.52 µg m⁻³ (Table 1), which showed that many samples in this study exceeded the national air quality standard of 35 µg m⁻³ for 24-hour PM_{2.5} established by the U.S. Environmental Protection Agency. Fig. 1 shows the comparison of PM_{2.5} mass concentrations during the southwest (this study) and northeast season (Ee-Ling *et al.*, 2015) at Bangi in Malaysia. Additionally, those at other cities with different average time (Keywood *et al.*, 2003; Ee-Ling *et al.*, 2015) are also shown for reference. There are significant differences in PM_{2.5} mass concentrations between the samples during the southwest monsoon (this study) and northeast seasons (Ee-Ling *et al.*, 2015) at Bangi.

Carbonaceous Components

OC and EC

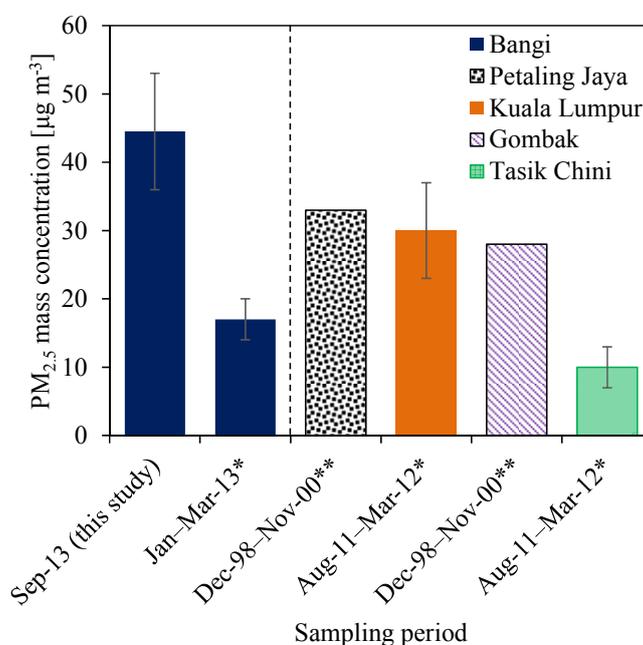
Mass concentrations of OC and EC were 10.7 ± 3.17 and 4.11 ± 0.916 µgC m⁻³, respectively (Table 1). The OC/EC mass ratios were 2.69 ± 0.935. In other Southeast Asian countries, the mass concentrations of OC and EC in PM_{2.5} were 9.42 ± 1.97 and 3.23 ± 0.795 µgC m⁻³, respectively in Riau, Indonesia (Fujii *et al.*, 2014a); 3.45 ± 1.67 and 1.78 ± 1.13 µgC m⁻³, respectively during clear days in Singapore (See *et al.*, 2006); 18.3 ± 11.9 and 2.7 ± 1.5 µgC m⁻³, respectively in Hanoi, Vietnam (Hai and Kim Oanh, 2013) and 9.5 ± 3.6 and 2.0 ± 2.3 µgC m⁻³, respectively in Phimai, Thailand (Li *et al.*, 2013). Relatively high OC and EC concentrations of this study compared to those of other Southeast Asian countries were observed, which indicates that significant sources of OC and EC exist.

Char-EC and Soot-EC

Photochemical reactivity of organic components can influence OC/EC ratios in PM_{2.5}; however, char- and soot-EC are not affected (Han *et al.*, 2008). Thus, the char-EC/soot-EC ratio is suggested as a useful indicator of pyrogenic source contributions such as vehicle and biomass burning emissions. This is because char-EC is formed under lower combustion temperatures, which occurs in biomass burning, whereas soot-EC is formed under higher combustion temperatures such as coal combustion or internal engine combustion (Zhu *et al.*, 2010; Chuang *et al.*, 2013). Char- and soot-EC have been defined by Han *et al.* (2007). In this study, the

Table 1. The statistical results regarding PM_{2.5} mass concentrations and chemical speciation.

	Range (min–max)	Average ± Standard deviation
PM_{2.5} mass [$\mu\text{g m}^{-3}$]		
PM _{2.5}	34.6–59.5	44.5 ± 8.52
Carbonaceous components [$\mu\text{gC m}^{-3}$]		
OC	7.97–17.6	10.7 ± 3.17
EC	2.83–5.45	4.11 ± 0.916
char-EC	2.58–5.18	3.85 ± 0.893
soot-EC	0.177–0.333	0.265 ± 0.0489
Metals [ng m^{-3}]		
Al	51.1–269	178 ± 72.0
Si	198–650	424 ± 175
K	718–1150	877 ± 171
Ca	56.3–183	112 ± 45.7
Ti	6.13–21.5	13.0 ± 5.17
Fe	49.8–197	102 ± 49.1
Zn	29.8–83.0	58.9 ± 19.1
Pb	0.822–143	37.4 ± 45.5

**Fig. 1.** Comparison of daily PM_{2.5} mass concentrations at Bangi and other cities in Malaysia. Error bars indicate standard deviations. (*data from Ee-Ling *et al.* (2015); **data from Keywood *et al.* (2003).)

mass concentrations of char-EC and soot-EC were 3.85 ± 0.893 and 0.265 ± 0.0489 $\mu\text{gC m}^{-3}$, respectively (Table 1), indicating that EC was primarily composed of char-EC. This finding demonstrates that EC emission sources at lower combustion temperature were dominant.

For comprehensive discussion of EC emission sources, the relationship between char- and soot-EC mass concentrations is plotted in Fig. 2. The char-EC/soot-EC ratios ranged from 10.7 to 19.5. It is reported the char-EC/soot-EC ratios were 22.6 for biomass burning, 1.31 for coal combustion, and 0.60 for motor vehicle exhaust (Chow *et al.*, 2004; Han *et al.*, 2008). Thus, our results strongly suggest that biomass burning is the main contributor to ambient EC concentrations compared to coal combustion and motor vehicle emissions.

As a possible biomass burning source during the sampling periods, Indonesian peatland fire source is suggested based on the data of daily hotspot counts in the Sumatra Island (Fig. 3) and the results of backward air trajectories (Fig. 4).

Metals

The statistical results of individual metal concentrations are shown in Table 1. K was the dominant species at 0.877 ± 0.171 $\mu\text{g m}^{-3}$, followed by Si at 0.424 ± 0.175 $\mu\text{g m}^{-3}$ and Al at 0.178 ± 0.0720 $\mu\text{g m}^{-3}$. Enrichment factors shown in Fig. 5 were calculated using equation (1) to determine the source of each individual metal, where $([X]/[Al])_{\text{Air}}$ and $([X]/[Al])_{\text{Crust}}$ are the mass ratio of a metal (X) to Al in PM_{2.5} and Crust, respectively.

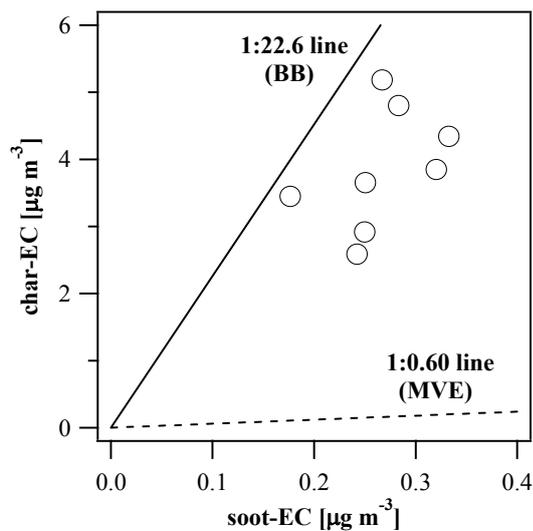


Fig. 2. Plot of char-EC vs. soot-EC concentrations (BB = biomass burning, MVE = motor vehicle exhaust).

$$\text{Enrichment factor} = \frac{([X]/[Al])_{\text{Air}}}{([X]/[Al])_{\text{Crust}}} \quad (1)$$

The reference crust data (Taylor, 1964) was used for calculation of $([X]/[Al])_{\text{Crust}}$. The enrichment factors for Si, Ca, Ti, and Fe were 0.727 ± 0.194 , 1.34 ± 0.490 , 1.10 ± 0.280 , and 0.872 ± 0.268 , respectively, which suggest that these metals were derived from soil dust. In contrast, enrichment factors for K, Zn, and Pb were much higher than 1.00, at 24.1 ± 16.1 , 510 ± 450 , and 1380 ± 1390 , respectively. This indicates that these metals were derived from anthropogenic emissions, likely biomass burning for K and vehicle-related emissions from tire, clutch, and brake wear for Zn and Pb as discussed in the former report (Wahid *et al.*, 2014).

PM_{2.5} Chemical Mass Closure

To clarify the major sources of $PM_{2.5}$ in this study, the

mass closure model was employed. We considered seven categories in this model: organic matter (OM), EC, ammonium, sulfate derived from non-sea salt (nss-sulfate), potassium derived from non-sea salt (nss-potassium), sea salt and crustal matter. The data of inorganic ion concentrations were provided from our former results during the sampling periods (Fujii *et al.*, 2014b). The amount of OM was equal to that of OC multiplied by 2.1, which is a widely used OC to OM conversion factor for non-urban aerosols (Turpin and Lim, 2001). Concentrations of nss-sulfate, nss-potassium, and sea salt were calculated from Eqs. (2)–(4) from sea water composition (DOE, 1994). Concentrations of crustal matter were calculated using Eq. (5).

$$[\text{nss-sulfate}] = [\text{sulfate}] - 0.252[\text{sodium}] \quad (2)$$

$$[\text{nss-potassium}] = [\text{potassium}] - 0.0370[\text{sodium}] \quad (3)$$

$$[\text{sea salt}] = 1.47[\text{sodium}] + [\text{chloride}] \quad (4)$$

$$[\text{crustal matter}] = 1.16(1.19[\text{Al}] + 2.15[\text{Si}] + 1.41[\text{Ca}] + 1.67[\text{Ti}] + 2.09[\text{Fe}]) \quad (5)$$

A factor of 1.16 is used to compensate for the exclusion of MgO, Na₂O, K₂O, and H₂O from the crustal mass calculation (Mkoma *et al.*, 2009).

The mass concentrations of seven categorized sources in $PM_{2.5}$ mass are shown in Fig. 6. OM was the most abundant component in $PM_{2.5}$ mass at $22.4 \pm 6.65 \mu\text{g m}^{-3}$, followed by nss-sulfate at $4.84 \pm 2.49 \mu\text{g m}^{-3}$, EC at $4.11 \pm 0.916 \mu\text{g m}^{-3}$, and crustal matter at $1.76 \pm 0.710 \mu\text{g m}^{-3}$. Thus, sources of carbonaceous $PM_{2.5}$ (OM and EC), which account for $60.6 \pm 15.5\%$ in $PM_{2.5}$ mass, should be identified to improve air quality in this study field. Indonesian peatland fires during this period, local biomass burning activities such as meat and fish cooking in Bangi, where there are stalls that sell the local grilled meat dish and secondary aerosol formation are suggested as possible sources of carbonaceous $PM_{2.5}$.

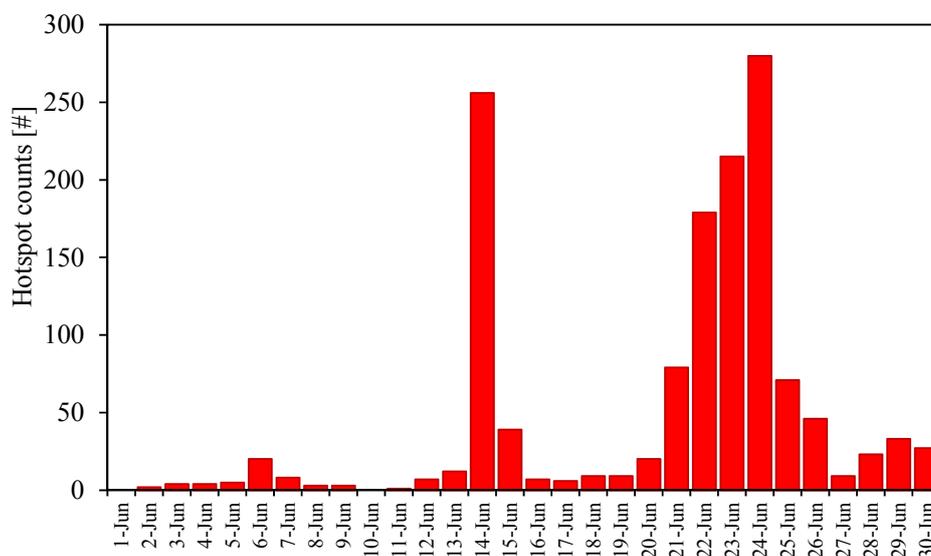


Fig. 3. Daily hotspot counts in the Sumatra Island. (Hotspot counts detected by the NOAA-18 satellite (Indofire)).

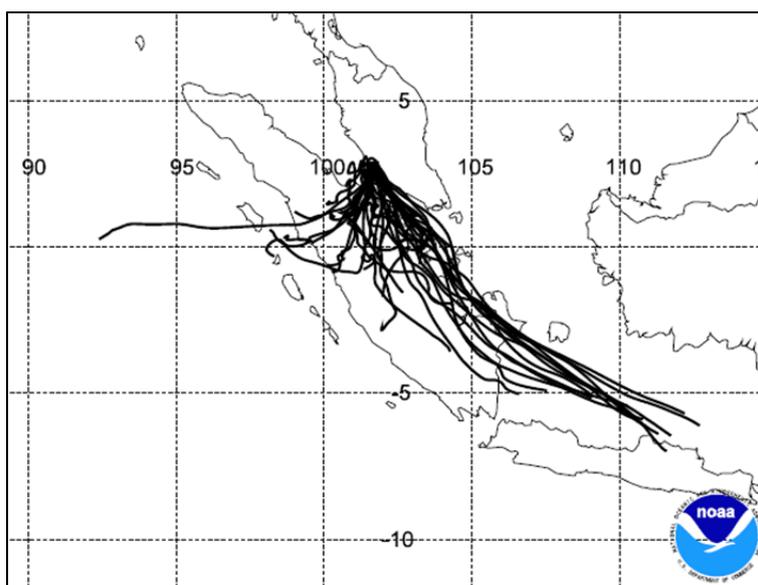


Fig. 4. Backward air trajectories during the sampling periods. (The 3-days backward air trajectories every 6 hours with 500 m above ground level arriving at the sampling site in local time were calculated during the sampling periods by the Hybrid Single Particle Lagrangian Integrated Trajectory model (Draxler and Hess, 2004) based on meteorological data obtained from the Global Data Assimilation.)

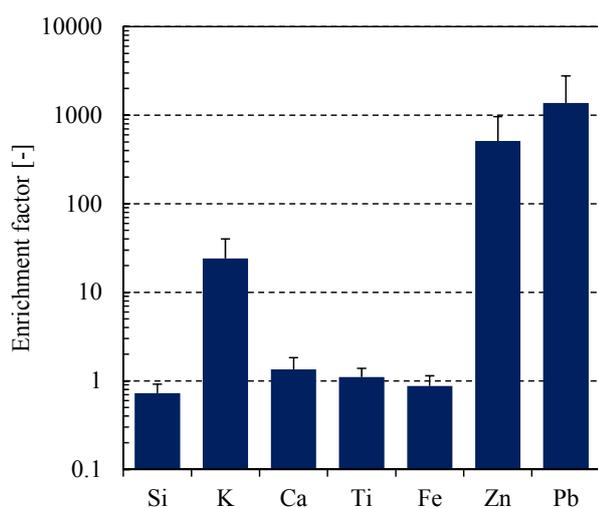


Fig. 5. Enrichment factor of metals with Al as the reference metal for crustal source.

However, our data cannot provide detailed source contributions to $PM_{2.5}$ using source profiles on the basis of carbonaceous species.

CONCLUSIONS

A case study was carried out to characterize ambient $PM_{2.5}$ based on ground-based sampling in Bangi, Selangor, Malaysia in September 2013 during the southwest monsoon season. The mean $PM_{2.5}$ mass concentration was $44.5 \mu\text{g m}^{-3}$, indicating that it exceeded the national air quality standard of $35 \mu\text{g m}^{-3}$ for 24-hour $PM_{2.5}$ by the U.S. Environmental Protection Agency. Relatively high OC and EC concentrations of this study compared to those of other

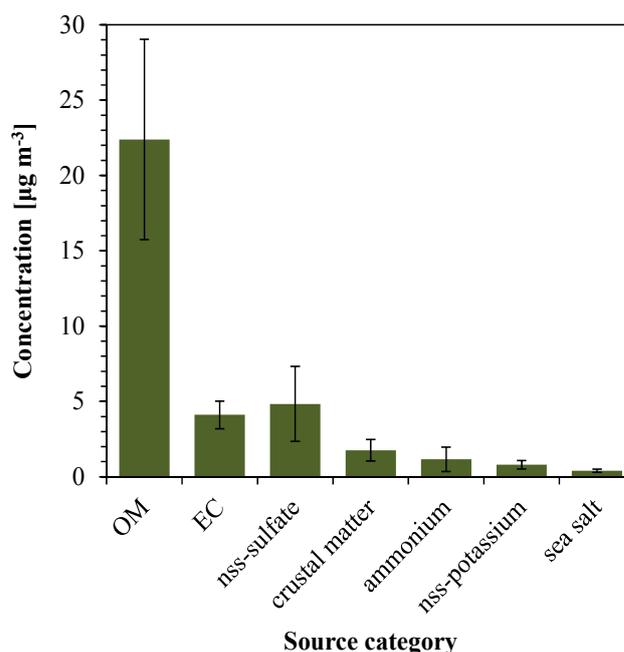


Fig. 6. Seven categorized sources contributions to $PM_{2.5}$ mass by using aerosol chemical mass closure model. Error bars indicate standard deviations.

Southeast Asian countries are observed, which indicate that significant sources of OC and EC exist. The results of char-EC/soot-EC ratios strongly suggest that biomass burning is the main contributor to ambient EC concentrations compared to coal combustion and motor vehicle emissions. From calculations using the mass closure model, OM was the most abundant component in $PM_{2.5}$ mass at $22.4 \pm 6.65 \mu\text{g m}^{-3}$, followed by nss-sulfate at $4.84 \pm 2.49 \mu\text{g m}^{-3}$, and EC at

$4.11 \pm 0.916 \mu\text{g m}^{-3}$. This result indicates that targeting the sources of carbonaceous PM_{2.5} is a crucial step to improve the air quality in this study field.

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