Dissertation

Investigation of status, characteristic, and emission sources of airborne ultrafine particles in Indonesia

Graduate School of Natural Science and Technology

Kanazawa University

Japan

Division of Environmental Design

Student ID No. (1924052006)

Name: Muhammad Amin

Chief advisor: Professor Furuuchi Masami

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Abstract

In this study, the particulate matters down to the ultrafine particles (UFPs) were evaluated to discuss the status, characteristic, and also their sources in Indonesia during diurnal and nocturnal times, dry and rainy season, and also before and during the COVID-19 outbreaks. Ambient nano sampler was used to collect the samples and then analyzed its carbon components by using the IMPROVE-TOR protocol. Air mass trajectory was overlapping with the hotspot information to discuss the possible influence of biomass burning. Regardless the interval times, the UFPs were stable both diurnal and nocturnal with slightly higher during diurnal due to the lower planetary boundary layer (PBL). EC concentration, particularly soot-EC was higher during diurnal than nocturnal due to the higher number of vehicles. Seasonal different of UFPs in Indonesia was founded in the east coast of Sumatra Island in where the biomass burning particularly from peatland fires was contributed. In contrast, in the west coast of Sumatra Island, throughout the year, the PMs level was very stable because the similarity of the air mass origin in both rainy and dry seasons. Then, the PMs level during the covid-19 pandemics was totally decrease especially for UFPs, up to 68% compared with the value before the pandemics. It was in line with the soot-EC concentration where during the pandemics, it was 2 to 14 times lower than before the pandemic covid-19 because of the decreasing of vehicles used.

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Chapter I
Introduction

1.1. Background

Ambient particulate matters (PMs) are composed both primary and secondary sources from anthropogenic or natural sources and by conversion process from gas-to-particle such as nucleation and condensation **(Kumharn and Hanprasert, 2016; Inoue, 2018; Moran et al., 2019; Chalermpong et al., 2021)**. Their diameter can be ranging from several nanometers to 100 μm. The smaller the particle, the easier penetrate to the human body **(Xing et al., 2016; Schraufnagel, 2020),** especially respiratory system, the more harmful its effect to the human health **(Pope et al., 2009; Heft-Neal et al., 2018; Wang et al., 2019)**. Ultrafine (UFP) or Nanoparticle (NP) for instance, the PMs with size less than 100 nm, has ability to penetrate into the deepest part of human respiratory system and even enter the bloodstream which induce the inflammation and catalyze the cardiovascular and respiratory diseases in the human body **(Choomanee et al., 2020; Luo et al., 2019; Nuthammachot et al., 2019; Adam et al., 2021)**.

PMs with size smaller than 1 μm as well could penetrate into the alveolar region of the lungs **(Balakrishnajah et al., 2012)**. Not only fine or ultrafine particle, PM_{10} and TSP also important due to its contribution to the exacerbation of asthma attacks **(Pope et al., 2009; Chelani et al., 2010)**. Hence, size-segregated of PMs research is very essential to understand comprehensively about the particle pollutant in an area.

Chemical component in PMs size-segregated is also an important issue since its linked directly to the human and environmental problem such as carbonaceous component **(Fan et al., 2014; Huang et al., 2019)**. Due to such reason, recently, carbonaceous aerosol has been receiving increased intentions. Its commonly divided into organic (OC) and elemental carbon (EC). OC can be produced by primary and secondary sources **(Jones and Harrison, 2005; Saylor et al., 2006)**, while EC is emitted only from primary source. Both of OC and EC are caused health and environmental problem and are the dominant chemical component in size-segregated of PMs including $PM_{0.1}$ **(Phairuang et al., 2021; Putri et al., 2021)**.

In recent decades, several studies have been published their findings related to size-fractionated of PMs including some of chemical composition such as carbonaceous component, water-soluble inorganic ions, and metals at different location across the world **(Tursic et al., 2006; Zhang et al., 2018; Zu et al., 2018; Rovelli et al., 2020)**. However, in developing countries, which faces the limitation taking into account the institution, financial, and technology, the studies related to the PMs size-distribution down to nano size is very scarce

(Amin et al., 2021; Phairuang et al., 2021; Putri et al., 2021). In Indonesia, to the best of authors knowledge, this issue is not covered yet. As a result, the understanding about the behavior of PMs including their effect to the citizens health was very poor and affected to the lack of regulation and policy to tackle the air pollution problem in Indonesia.

Sumatra Island, as the largest island among five major islands in Indonesia, faces the serious air pollution problem in several cities due to some sources. In east coast of Sumatra Island for example, forest fires especially in the peatland areas occurred annually and emitted a large amount of PMs to the atmosphere and even caused several health issues **(Betha et al., 2013; Koplitz et al., 2016; Tham et al., 2019)**. In urban area which many industries constructed and the increasing of vehicle users, the air pollution problem cannot be ignored as seen in Batam, Medan, and Pekanbaru cities, in Sumatra Island, Indonesia.

Based on the background behind the data unavailability, it is urgently required to conduct the comprehensive studies of size-segregated of PMs along with the chemical composition in different characteristic sites, interval times and season, Indonesia. So then, it can be used by the stakeholders as a basic data to propose the policy and regulation to tackle this issue in Indonesia.

1.2. Research objectives

The objectives of this study are comprehensively evaluated the size-segregated of PMs including UFP and also estimate the PMs emission factor of peat soil burning to estimate the total peatland fire emission in Sumatra Island, Indonesia as well as the chemical composition particularly carbonaceous components. The specific aims of this study, are:

1. Evaluate the PMs size distribution in different characteristic sites and interval time and season
2. Evaluate the carbonaceous component of PMs in in different characteristic sites and interval time and season
3. Findings the emission factors of peat soil open burning for estimation the total emission of peatland fires in Sumatra Island, Indonesia

The summarize the research questions and objectives are listed in the **Table 1.1.**

Table 1.1. Research questions and objectives of each chapter in this study

Chapter	Research question	Objectives
4	Does diurnal and nocturnal affect the level of UFP?	To overview the different of PMs level at diurnal and nocturnal

	Does the carbonaceous component in UFPs differ between diurnal and nocturnal?	To obtain the different of carbonaceous component at diurnal and nocturnal
	What are the dominant sources of PMs at diurnal and nocturnal?	To obtain the significant sources of PMs at diurnal and nocturnal
5	Does the concentration level of PMs differ between cities in Sumatra Island?	To overview the different of PMs level at different characteristic cities in Sumatra Island
	Does concentration and carbonaceous pattern differ between rainy and dry season?	To overview the different of PMs level at different season in Sumatra Island
	What are the dominant sources of PMs and carbonaceous component during rainy and dry season?	To obtain the significant sources of PMs at different season in Sumatra Island
	What are the dominant sources of PMs and carbonaceous component in the different cities in Sumatra Island?	To obtain the significant sources of PMs at different cities in Sumatra Island
	What is the effect of meteorological characteristic to the PMs level in Sumatra Island	To obtain the effect of meteorological condition to the PMs level in Sumatra Island
6	Does the covid-19 pandemics affect to the PMs level in Sumatra Island?	To obtain the PMs level during covid-19 pandemics
	What are the main sources of PMs during the covid-19 pandemic in Sumatra Island?	To obtain the sources of PMs during the covid-19 pandemics
	How is the carbonaceous component of PMs during covid-19 pandemic in Sumatra Island?	To obtain the characteristic of carbon component during the covid-19 pandemic

1.3. Framework, originality, and research scope

As shown in the **Figure 1.1.** the framework of this study can be divided into three parts i.e. emission status and characteristic and the emission sources of UFP in Sumatra Island. The first and the second parts aim to evaluate UFP level as well as its characteristic in Sumatra Island at different interval time (diurnal and nocturnal), different cities (Padang, Jambi and

Pekanbaru), different season (rainy and dry), and also during the covid-19 pandemics. While the latter part is the emission sources which aims to evaluate the origin of emission of UFPs in Sumatra Island.

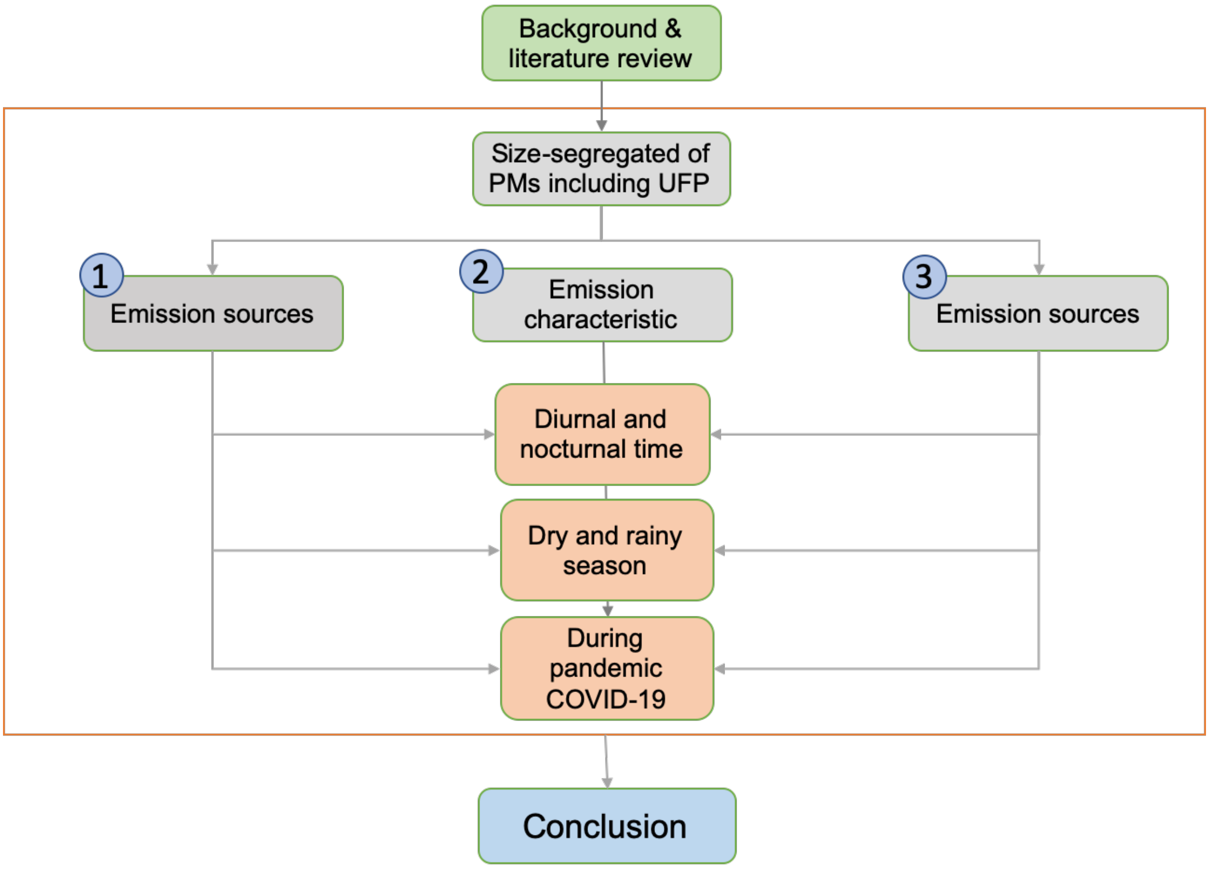

Figure 1.1. Research framework

In Indonesia, since 1980s, the increasing of studies related to PMs in several characteristic areas has occurs, however, the recent study has the following originality and also the uniqueness as

1. The used of ambient Nano samplers (ANS) can specify the particle in the different sizes even particle less than 0.1 μm or UFP
2. The chemical characteristic of size-segregated of PMs can specify the contribution of each sources in specific size of particle
3. The different of interval time, and season, and during the covid-19 pandemics of sampling period can reveal the sources contribution in each period

In the air quality monitoring, the size-segregated of PMs especially down to UFP becomes important because of its effect which very harmful to the human health. They are varied across different interval time, location, and season, especially during covid-19 pandemics where the human activities almost stop in every aspect. By providing all the data togethers, it will become the first comprehensive data related to PMs in Sumatra island even in Indonesia.

Due to the limitation of resources, this study can evaluate only several cities in Sumatra Island where sometimes we run the sampling in parallel. Event though, this study cannot fully cover all the location in Sumatra Island, but it can cover several different location and time period even season which separated in several chapters. In the chapter 4, the different between diurnal and nocturnal time of size-segregated of PMs were evaluated while in chapter 5, the three different characteristic cities in two different seasons were examined. Then, in chapter 6, the effect of covid-19 pandemics to the PMs level was evaluated.

1.4. Outline of dissertation

The main focus of this study was to evaluate the size-segregated of PMs and carbonaceous component in different interval time, season, and location. The dissertation contains several chapters as shown below:

Table 1.2. The outline of the dissertation

Chapter	Name	Description
I	Introduction	Including background, research objectives, framework, originality, research scope, and outline of dissertation
II	Literature review	Contain PMs towards human health, size distribution of PMs including ultrafine particles and PMs studies in Indonesia: a review since 1990s
III	Methodology	Air sampler, sampling procedure including air and biomass sampling, open burning simulation, hotspot and airmass trajectory, chemical analyses

IV	Diurnal and nocturnal UFPs in Indonesia	To identify the different of PMs between diurnal and nocturnal both mass and chemical behavior
V	Rainy and dry season UFPs in Indonesia	To evaluate the PMs characteristic in different location and season including its carbonaceous components
VI	UFPs in Indonesia during the pandemic covid-19	To identify whether the covid-19 pandemic affect the UFPs level in Sumatra island, Indonesia
VII	Conclusion, policy suggestion, future direction, and limitation	Including the summary of the whole chapters and regulation proposed for the stakeholders and the limitation of this study

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Chapter II

Literature Review

2.1. Particulate matters towards human health

PMs in each size has its effect to the human health. PM_{10} and $PM_{2.5}$ in particular all inhalable of particle which are small enough to enter the respiratory system for instance the thoracic region. Many researchers have proved that inhalable PMs was very harmful to the human health both sort-term and long-term exposure **(Xing et al., 2016; Doherty et al., 2017; Manisalidis et al., 2020)**. Sort term exposure could be in hours or days while long term exposure could be in months and even years **(Cadelis et al., 2014; Chen et al., 2021).** Sort term exposure to the PMs such as PM_{10} published by **Weinmayr (2010)** affect the respiratory health. The effect of PMs to the mortality mostly due to the long-term exposure particularly in smaller particle size as $PM_{2.5.}$ and UFP **(Jung et al., 2020; Chen et al., 2021)**

As published by **WHO (2013),** the exposure to the PMs more harmful than ozone or common air pollutant as carbon monoxide to the human health **(WHO et al., 2013).** It was well-known that PMs formed by heterogeneous mixture of liquid and solid particles which suspended in the air. They are varied not only in sizes but also in chemical composition **(Martins et al., 2021).** The chemical composition for instance, they are differed from each source and each location. The general composition that evaluated by the researchers was nitrates, sulfates, carbonaceous component including organic and elemental carbon, organic compound as polycyclic aromatic hydrocarbons or PAHs, and even trace meal such as chromium, manganese, copper, zinc, etc **(Samek et al., 2017; Jandacka et al., 2021).** Those chemicals could be accumulated in the human body and affected several diseases even mortality **(Morakinyo et al., 2016; Poursafa et al., 2015).**

Generally, the magnitude of effect of PM exposure to the human health depends the physical characteristic of each person such as inhalation rate, breathing mode, and also lung volume of each person, however, the particles size of PMs has concluded that it has been linked directly as the vital cause of health problems **(Huang et al., 2017; Gupta and Alumalai., 2017).** The smaller particle sizes are deeper their penetrate to the human respiratory system. As shown in **Fig. 2.1** reported by **Londahl et al., (2006)**, the PMs associated with the health effect mostly in size smaller than 10μm. In the figures, coarse particles or 10 μm, mainly accumulated in the nasal-breathing such as nose and trachea. However, it will be removed by some process like sneezing and coughing **(Cadelis et al., 2014)**. Then, the particles with diameter size around 5 μm mostly deposited in the tracheobronchial tree. The smaller size between 1 and 5 μm is penetrated deeper and collected in the alveoli area. It is location where the gas exchange occurs. Based on previous report, the UFP, not only collected in the alveoli but could be accumulated in the blood and brain system of human that is the most harmful to the human health **(Ohlwein et al., 2019).**

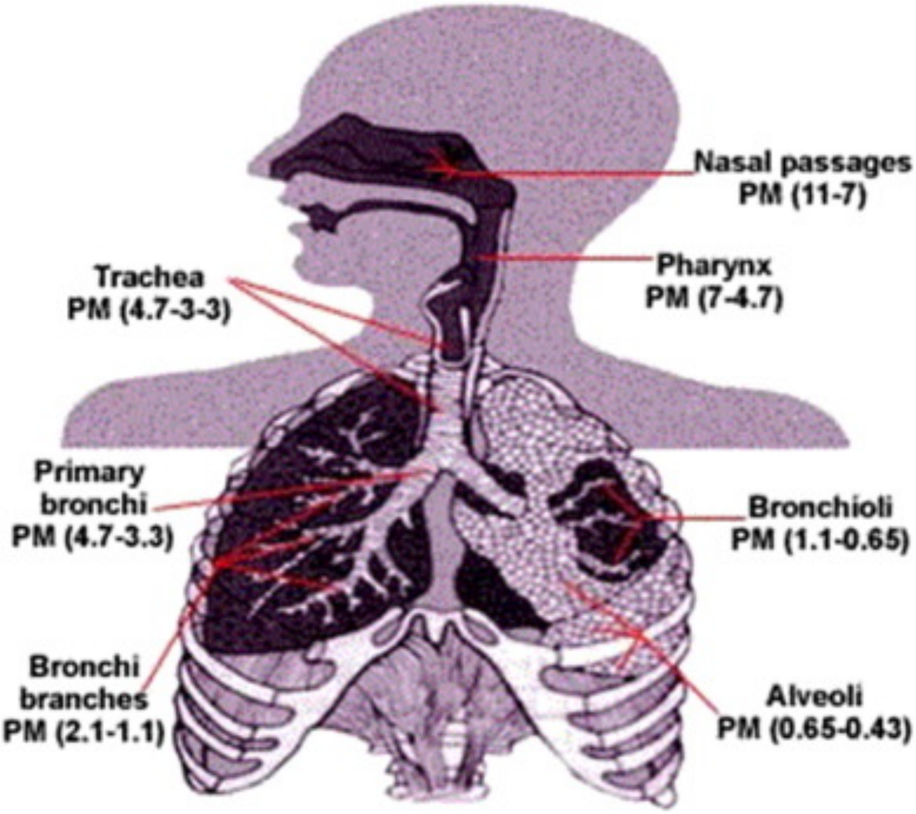

Fig. 2.1. The possible deposition location of PMs based on size into human body **(source: Londahl et al., 2006)**

2.2. Size distribution of particulate matters including ultrafine particles

In general, PMs is divided in three modes i.e. ultrafine including nucleation and Aitken mode with diameter less than 0.1 μm, fine (mostly accumulation mode, with diameter less than 2.5 μm) and coarse (with the aerodynamic diameter between 2.5-10 μm). Hence, the sizes of particles suspended in the atmosphere can be ranging from nanometer size to around tens micrometers. In detail, the figure of PMs in different modes was shown in **Fig. 1.** As shown, the UFP which was the highest taking into account the number concentration, in contrary, it was the smallest in the mass and volume unit **(NARSTO, 2004)**. However, UFP are the main focus of researchers to investigate its correlation into human health **(Kumar et al., 2013; Schraufnagel., 2020).**

Different particle size, different their residence time in the atmosphere. Coarse particle size deposited quicker to the ground due to its gravity than the smaller sizes. $PM_{2.5}$, PM_1, and UFP can be stay on the orders of times even a few days. It will be removed from the atmosphere by natural event such as wet deposition by rain, dry deposition by its gravity and surface turbulence, and also by snow or fog. By meteorological condition, i.e. wind speed, wind direction, temperature and humidity, during their residency in the atmosphere, PMs could be transported from its original sources area to other area such as from urban to rural or from rural area to urban area and experienced both physical and chemical processes.

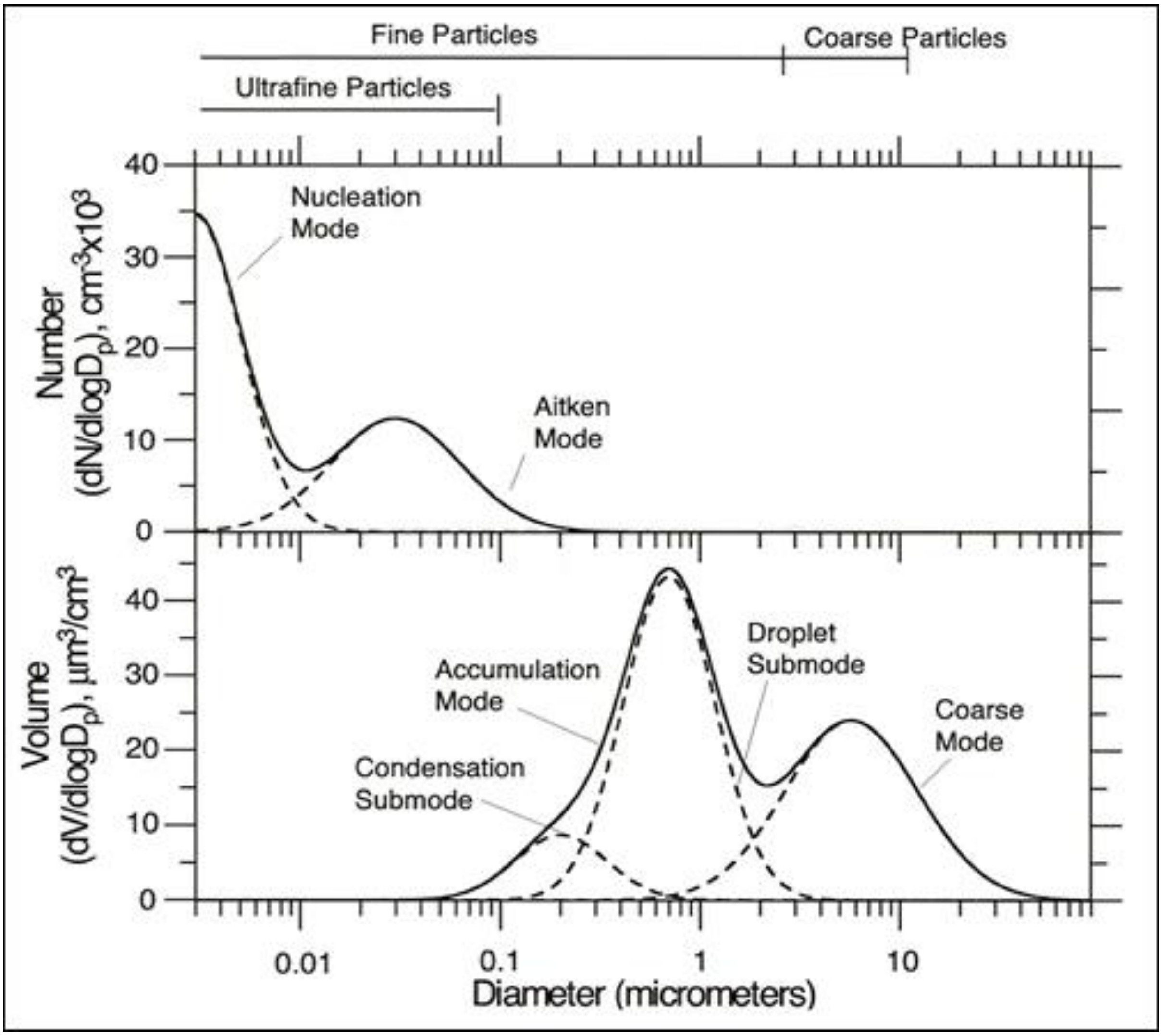

Fig. 2.2. The number and mass of size-distribution of PMs (sources: NARSTO, 2004)

2.3. Particulate matters studies in Indonesia: a review since 1990s

Indonesia is one of the developing countries in SEA. Every year, the population in Indonesia has growth significantly and is the highest among the Asian countries **(BPS Indonesia, 2021).** The increasing of population lead to the increasing of economic activities and also urbanization. The user of motor vehicles increases significantly year by year and contribute to the decreasing of air quality. Open biomass burning particularly from forest fires which commonly occurs in several areas of Indonesia also emitted a lot of pollutant, particulate matters for instance. The decreasing of air quality affected health and environmental effect in Indonesia even caused mortality. One of the most important pollutant regarding the air pollution in Indonesia is particulate matters (PMs) **(Betha et al., 2013, Amin et al., 2021).** Due to those issues, the studies related to PMs in Indonesia have been done in several cities and characteristic sites In Indonesia.

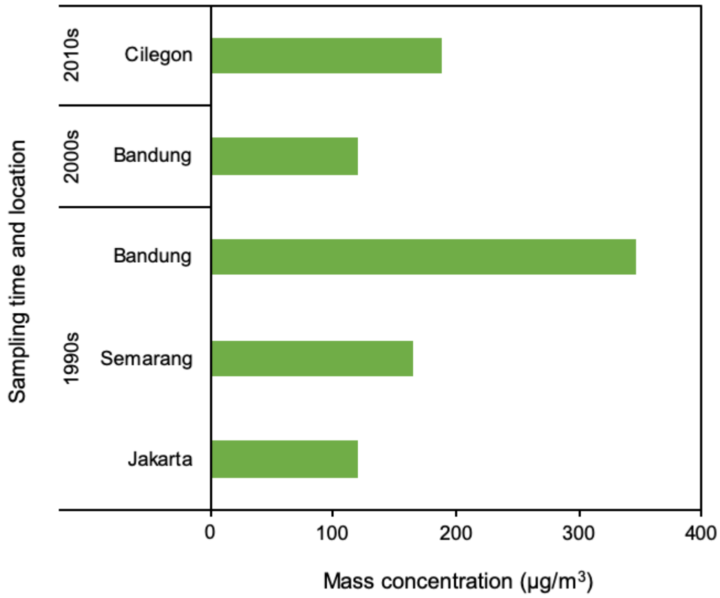

Figure 2.3. Mass concentration of TSP in Indonesia since 1990s

Based on the data recorded in the Scopus and Web of Science (WoS), the first study related to the PMs status in Indonesia have been done in 1980s by **Mukai et al., (1993).** They evaluated the Pb level in the airborne PMs in several location in Jakarta, the capital city of Indonesia. The level of Pb was ranged from 1.7 – 3.59 $\mu g/m^3$.

In 1990s, the studies related PMs was increased gradually. The sampling site is not only located in Jakarta but also in several cities in Indonesia, such as Semarang, Central Java, Jambi and Bukittinggi in Sumatra Island and also in Pontianak **(Browne et al., 1999; Kunii et al., 1997: Maenhaut et al., 2002)**. The issues were predominantly related to open biomass burning from forest fires in Sumatra and Kalimantan island which PM_{10} was the main PMs target during this period **(Betha et al., 2013; Fujii et al., 2015).**

In 2000s, the PMs studies in Indonesia increased more than 3 times compared to the 1990s. The main focus of PMs not only for PM_{10} and TSP but also fine particles or $PM_{2.5}$. However, the sites were predominantly in Java island which focus on anthropogenic sources such as industrial area, and emission from transportation. Several researchers focused on the forest fires issues which basically occurred in Sumatra and Kalimantan Island **(Hayasaka et al., 2014).** Not only the PMs level, in 2000s, many researchers also discussed the chemical composition of PMs such as carbonaceous component, trace metals, ions and PAHs **(Betha et al., 2013; Fujii et al., 2015).**

In 2010s, the studies related to PMs increased significantly and many researchers tried to evaluate the air quality in Indonesia not only focus in Java island but also in other major island except in Papua **(Rashid et al., 2014; Sattar et al., 2014).** However, most of the PMs targets was fine and coarse particles such as $PM_{2.5}$, PM_{10}, and TSP. The chemical components of PMs also evaluated to discuss the possible sources of them, however, no studies combined for all the PMs size including UFP which is one of the most important PMs size recently.

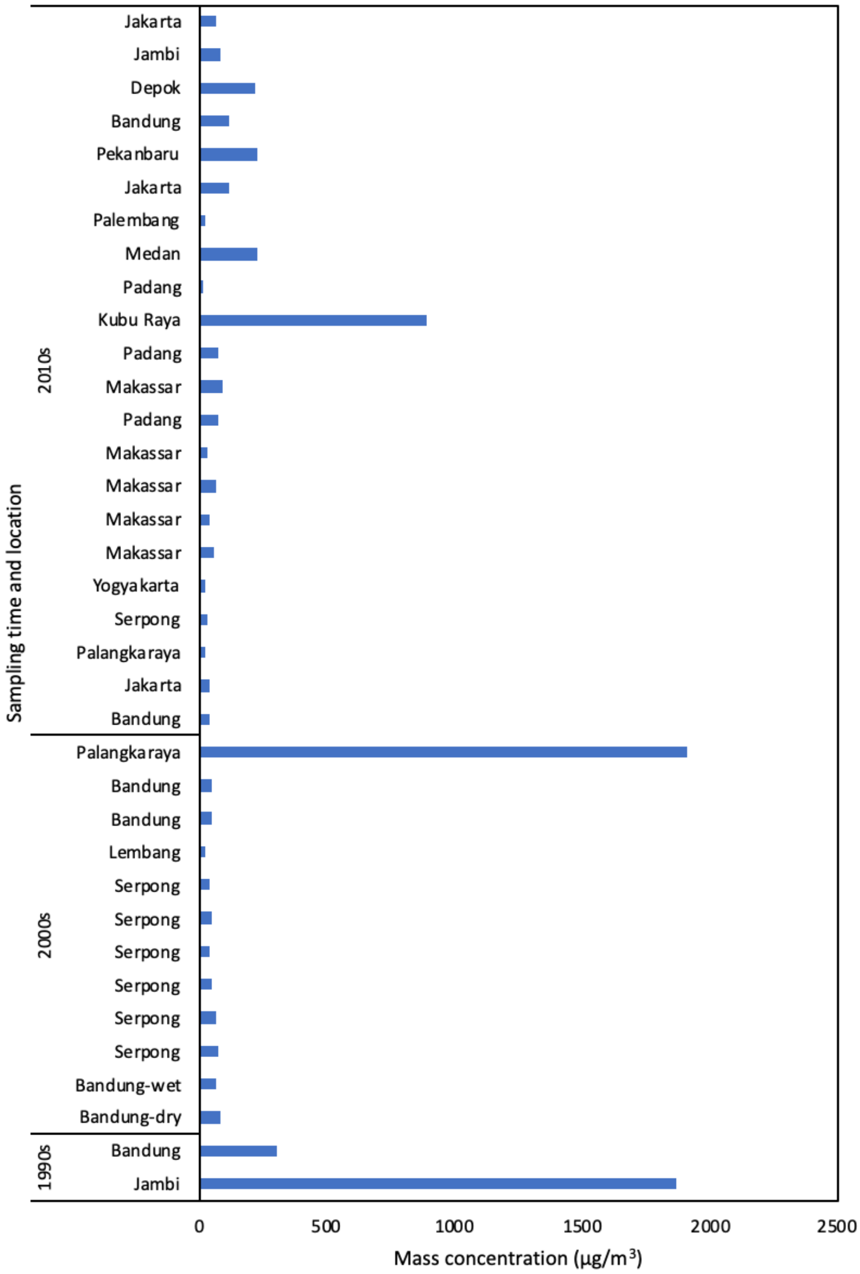

Figure 2.4. Mass concentration of PM_{10} since 1990s in Indonesia

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Chapter III
Methodology

Since the methodology for whole studies or Chapter IV, V, and IV was commonly similar. The description of each method including air sampling, chemical analyses, the distribution of hotspot as a representative of biomass burning, and the air mass backward trajectory to each study site were discussed in this chapter. As to the sampling site, it will be discussed in each chapter. Hence, the detail of common methodologies is discussed in the following sub-chapter as below:

3.1. Ambient particulate matter sampler

The cascade type air sampler or ambient nano sampler (ANS) were used in this study. It was developed by **Furuuchi et al., (2010)** in Kanazawa University. ANS contains six stages in where filters were installed to capture the size segregated of particles at flowrate 40 *l*/m. The **Fig.1** below shown the detail of ANS. The sampler consists inertial filter (IF) to specify the nano size of particle. Originally, the cut of size of the sampler was ~70 nm, then it was adjusted to 100 nm by modify the nozzle of the IF **(Furuuchi et al., 2010; Kumsanlas et al., 2020).**

3.2. Sampling procedures

The ANS used in this study contains six stages in where the filter was installed to capture the size segregated of particles at flowrate 40 *l*/m. Quartz fibrous filters (QFF) (2500 QAT-UP, Pall Corp., New York, USA) of ∅55 mm in diameter were used in the stage one to six and in the last stage as well or backup filter (BF). In the five stages, inertial filter (IF) were used to separate the particle in the nano size range or $PM_{0.1}$ which further collected at BF. A cartridge of IF consisted of webbed stainless-steel fibers with average diameter of fiber is around 9.8 μm (Nippon seisen Co. Ltd, Osaka, Japan, felt type, SUS-316). It was inserted into a cartridge. The diameter of the cartridge nozzle is ∅ 5.25 mm. Beforehand, the stainless-steel web fiber was cleaned with ethanol. This step is very important, so the blank value of the carbon in that filter is small enough. For QFF, it had been pre-baked at 350^{o}C for 1 h in an oven following the standard proposed by Ministry of Environment of Japan **(MOEJ, 2019).** Both of types filters were then conditioned in the $PM_{2.5}$ chamber for 48 h before and after sampling. The chamber was operated with temperature and humidity at 21.5±1.5 ^{o}C and 35±5% RH, respectively. Each filter was covered by aluminum foil and then keep them in the zip lock type plastic bag. During the transportation from Kanazawa, Japan to each sampling site and vice versa, all of filters were accompanied by several blank filters to examine the possible contamination.

3.3. Carbonaceous component analyses

The carbonaceous component (OC, EC, char-EC, and soot-EC) is one of the main important chemicals in the PMs. It can inform the characteristic of aerosol particle in the study area and the sources of the PMs. Hence, in all of the study, we analyze the carbonaceous component in all QFF by using a thermal/optical analyses types of carbon analyzer (Carbon Aerosol Analyzer, Sunset Laboratory, Tigard, OR 97223, USA), following the IMPROVE protocol **(Han et al., 2007; Kim et al., 2011a: 2011b)**. Each QFF sample was punched into 10 x 15 mm in size before placed into carbon analyzer. Briefly, the OC components were determined in the condition of 100% of helium for four steps or OC1 at 120°C, OC2 at 250°C, OC3 at 450°C, and OC4 at 550°C while EC fractions were determined in a mixture of 2% oxygen and 98% helium for three steps or EC1 at 550°C, EC2 at 700°C, and EC3 at 800°C. The total OC was defined as the sump up of OC1 + OC2 + OC3 + OC4 +PyOC, while the EC is obtained from EC1 + EC2 + EC3 – PyOC. PyOC is symbolized the pyrolyzed fraction of organic carbon. EC can be divided into char-EC and soot-EC **(Han et al., 2007; Han et al., 2009).** Char-EC, defined as EC1 – PyOC and soot-EC defined as EC2 + EC3. The repeatability of the analyses spot sample or QFF in stage 1, 2, 3, and 4, was performed. It confirmed to be comparable each of punched location with the CV value less than 3.2% for OC and 7.9 for EC, except in the first stage or particle >10 μm **(Putri et al., 2021; Amin et al., 2021).** The quality assurance and quality control (QA/QC) of carbon analyzer were evaluated by using a reference standard and travel blank filters for each study. A reference chemical used in the analyzes is sucrose ($C_{12}H_{22}O_{11}$) (196-00015, Sucrose, Wako Pure Chemical Industries, Ltd., Osaka, Japan) while the travel blank filter (n = 3 – 5) were confirmed to be small enough confirm to the minimum values of the sample in whole studies. The value of each sample was subtracted with the average travel blank values in each location to assure that the carbon component in the filter were generated only from the emission sources in the studied area.

3.4. Hotspot and air parcel trajectory

In this study, 72-h backward air mass trajectories arrived at each sampling site were calculated. The distance from the average ground level (a.g.l.) was 500 km as the concession between the model limitation and the data observed at the ground surface **(Murao et al., 2011, Budiawati et al., 2016)**. The Hybrid Single-Particle Lagrangian Integrated Trajectory Model version 4 (HYSPLIT4, http://ready.arl. noaa.gov/HYSPLIT.php, accessed between 2018-2020) was used (ARL., 2019). As to the hotspot that commonly used to represent the biomass burning at the ground surface, the meteorological data from Global Data Assimilation System (GDAS) resolution 0.5 degree from the National Oceanic and Atmospheric Administration (NOAA) of the Unites Stated of America (USA) were used. Geographic locations of hotspot in the study site were extracted from the Moderate Resolution Imaging Spectroradiometer (MODIS) which produced by NASA (https://firms.modaps.eosdis.nasa.gov/download/) (accessed on 15 August 2019) **(FIRMS, 2019).** The resolution of hotspot was used at 1 km x 1 km. While for the number of hotspots, the data produced by Asean Specialized Meteorological Centre (ASMC) was used which available online at www.asmc.asean.org **(ASMC, 2019)**. The secondary data such as meteorological condition including temperature, humidity, wind speed, wind direction, precipitation, sun shine, etc., was used to analyze the relationship between meteorological condition and PMs concentration and it was produced by each local government or Meteorological and Geophysical, Climatology Agency (BMKG, www.bmkg.go.id) of Indonesia **(BMKG, 2019)**.

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Chapter IV
Diurnal and nocturnal of UFPs in Indonesia

4.1. Objectives of the study

In this study the first step to understand comprehensively the present status, characteristic and emission sources of size-segregated PMs including $PM_{0.1}$, the different between two interval time i.e. diurnal or nocturnal were evaluated in Indonesia. Hence, the air samples were collected in Sumatra Island in two different sites or roadside and riverside from August 2^{nd} to 13^{th}, 2019. The carbonaceous component which is useful for the evaluation of characteristic in each interval time were examined. Those carbonaceous components were discussed along with meteorological condition such as the thickness of the mixing layer. Biomass burning represented by hotspot and emission traffic as well in study site was also examined to discuss the possible emission sources of PMs. Eventually, the backward air trajectory arrived at the study sites were also used along with the maps of hotspot in the study site.

4.2. Sampling sites

4.2.1. Site for the monitoring campaign

Two different sites for monitoring campaign were selected in Jambi City. These sites were located at roadside (RS) and riverside (RV) as shown in **Figure 1**. Jambi city is located in Jambi province. This province is of the province in Sumatra Island. In 2019, the total population of Jambi City is around 604,000. Reported by BMKG Indonesia, in this region, the monthly average temperature is ranged from 27.1 to 28.2^{o}C while the monthly average of the humidity is varied from 50 to 96% **(BPS Jambi, 2021)**. Such kind meteorological conditions should be affected the agglomeration of UFP. The altitude of Jambi city is 10 to 60 m which covers around 9.29 percent of Jambi Province or 4659 km^2 **(Dennis, 1990)**. As to the land use especially industrial area, reported by statistical agency (BPS) of Jambi City, there are 44 industries in this region consisted agricultural and forest product industry such as palm oil and rubber industry. Mining, metals, machinery, and the chemical industry also are among them. From the sampling site, these industries were located in southeast (SE), south (S), and southwest (SW). Jambi city, since 1990s already well-known as an area which annually face the biomass burning problem particularly from peatland fires during the dry season. In the study year in 2019, the total burned area in this province has increased significantly since 2017 **(KLHK, 2020)**. It is one of the expected sources because the sampling time were done also during the dry season or from August 2^{nd} to 13^{th}, 2019.

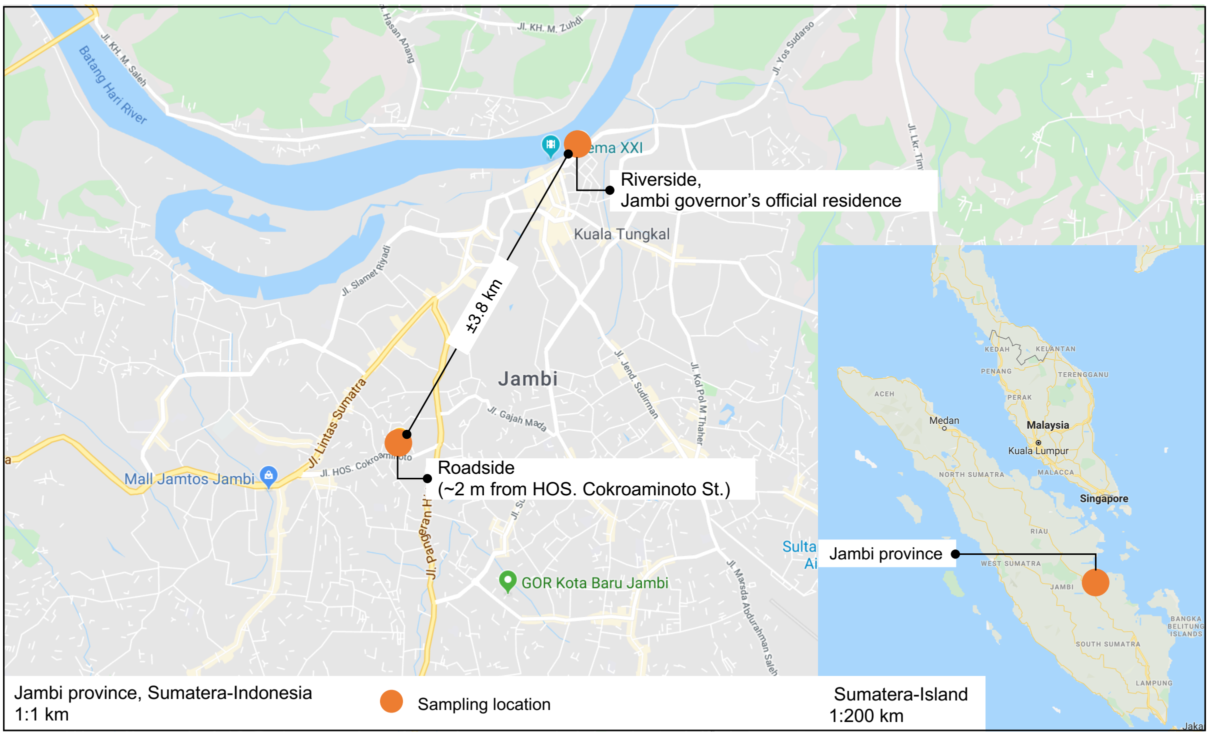

Figure 4.1. Sampling site at the roadside and riverside in Jambi city, Indonesia

The reason for selected the monitoring sites in roadside and riverside are due to both locations affected by different sources, particularly to UFP. The roadside was located beside the HOS. Cokroaminoto Stree, Suka Karya, Kota Baru District ((1°37′04.6″ S 103°36′01.2″ E) which is one the busiest street in Jambi city as seen from the number of vehicles passing through every day that are shown in **section 4.3**. The second sites or RV was located in the rooftop of the official offices of the Jambi Governors (1°35′17.5″ S 103°37′05.1″ E). It is near Raden Pamuk Street (~30 m) and Batanghari River (~115m). Batanghari river is the longest river in Jambi province which commonly used as the main transportation route between the Tanjung Jabung Timur district. The citizens of Jambi city used this river for school, work in offices, markets and tourists **(Zarmaili, 2015).** However, since the government built the bridge over the river in 2015, the used of Batanghari river as the main transportation route has significantly decreased **(Nurmalia, 2017)**.

Table 4.1. Sampling site, time, and its meteorological condition in Jambi city

Location	Term	Date (August 2019)	Time (Hours)	Total (n)	Temp (°C)	Humidity (%)	Pressure (kPa)	Wind Speed (m/s)
Roadside	Diurnal	2nd - 8th	11-12	7	32.4 ±0.7	48.2 ±3.3	100.9 ±0.2	1±0.2
	Nocturnal	2nd - 9th	11-12	7	26.9 ±0.3	61.4 ±11.4	100.9 ±0.2	1±0.2
Riverside	Diurnal	7th-12th	11-12	6	31.9 ±0.6	48.2 ±3.5	100.9 ±0.2	1±0.5
	Nocturnal	7th-13th	11-12	6	25.4 ±0.3	61.4 ±10.6	100.9 ±0.2	1±0.4

4.2.2. Reference site for the evaluation of biomass burning

As the reference data regarding the emission from biomass burning, a site located in the peatland field where the fires frequently occur were evaluate. The sampling was conduct in August 24th, 2019, in the Arang-arang village, Kumpeh Ulu subdistrict, Muaro Jambi regency at 11°35'43" in the South and 103°49'46" in the East **(BPS Muaro Jambi, 2021).** The sampling site was surrounded by plantation particularly palm oil. The detail sampling site was shown in **Fig. 4.2.**

Figure 4.2. Sampling site in roadside, riverside, and peatland area in Jambi city, Indonesia

4.3. Traffic amount

To discuss the different between diurnal and nocturnal, traffic influenced was one of the important factors. Hence, the traffic amount was counted manually by using handheld counters in both interval times, diurnal and nocturnal from 6:00 a.m. to 6:00 p.m. and from 6:00 p.m. to 6:00 a.m., respectively during the whole period in RS. However, in RV, these data were not counted due to logistical problem. The vehicles were classified into three categories i.e. motorcycles (MC), light vehicle or LV (cars and taxis) and heavy vehicle (HV) (trucks). These data are listed in **Table 4.2**

Table 4.2. Daily total number of vehicles in roadside during day and nighttime and its ratio in Jambi city

RS	Diurnal (D)			Nocturnal (N)			D/N		
	Motor cycle	Light Vehicle (LV)	Heavy Vehicle (HV)	Motor cycle	Light Vehicle (LV)	Heavy Vehicle (HV)	Motor cycle	Light Vehicle (LV)	Heavy Vehicle (HV)
n1	30602	15022	625	13108	6151	591	2.33	2.44	1.06
n2	24398	16533	741	17195	7079	378	1.42	2.34	1.96
n3	24034	14678	258	11036	5907	418	2.18	2.48	0.62
n4	29592	15081	758	11432	5402	620	2.59	2.79	1.22
n5	30857	14047	653	13734	5797	397	2.25	2.42	1.64
n6	28810	13818	626	14163	5414	511	2.03	2.55	1.23
n7	23520	13621	501	14358	6056	440	1.64	2.25	1.14
Ave	27402	14686	595	13575	5972	479	2.06	2.47	1.27

4.4. Result and discussion

4.4.1. Mass concentration of PMs

The average of mass concentration of each size range during diurnal (D) and nocturnal (N) times are shown in **Figure 4.3**. All the minimum, mean, and maximum values for 12 h sampling duration are listed in **Table 4.4.** as well as the values for PM size categories (PM0.1/1/2.5/10 and total suspended particulate (TSP)). The minimum, mean, and maximum concentration at day time were 11.7, 14.0±1.6 and 16.2 μg/m^3, respectively. These levels were increased at the night time to 21.5, 24.7±2.9, and 29.2 μg/m^3, respectively. In the present study, the daily average level of UFP in the roadside at 19.4 μg/m^3 was higher than levels recorded for other cities in SEA as seen from the **Table 4.3.** The comparison of average fraction between diurnal and nocturnal was displayed which shown that they were comparable taking into account of the location and times ranged from 17 ~ 19%, larger than that reported for other countries **(Hongtieab et al., 2020; Boongla et al., 2021)**. Compared to WHO guidelines (25 and 50 μg/m^3 for PM2.5 and PM10, respectively) all values for PM2.5 and PM10 were exceeded the standard in both sites **(PPRI No. 22, 2021).** These values also compared to National Air Quality Standard (NAAQS) of Indonesia which all of them was above the standard values except for PM2.5 in RV (53±13.9 μg/m^3) (Law of Indonesian Government No. 22/2021; 55 and 75 μg/m^3 for PM2.5 and PM10, respectively). Hence, all of the result shown that PMs levels and characteristics during diurnal and nocturnal in RS and RV were rather consistent with other locations in SEA countries.

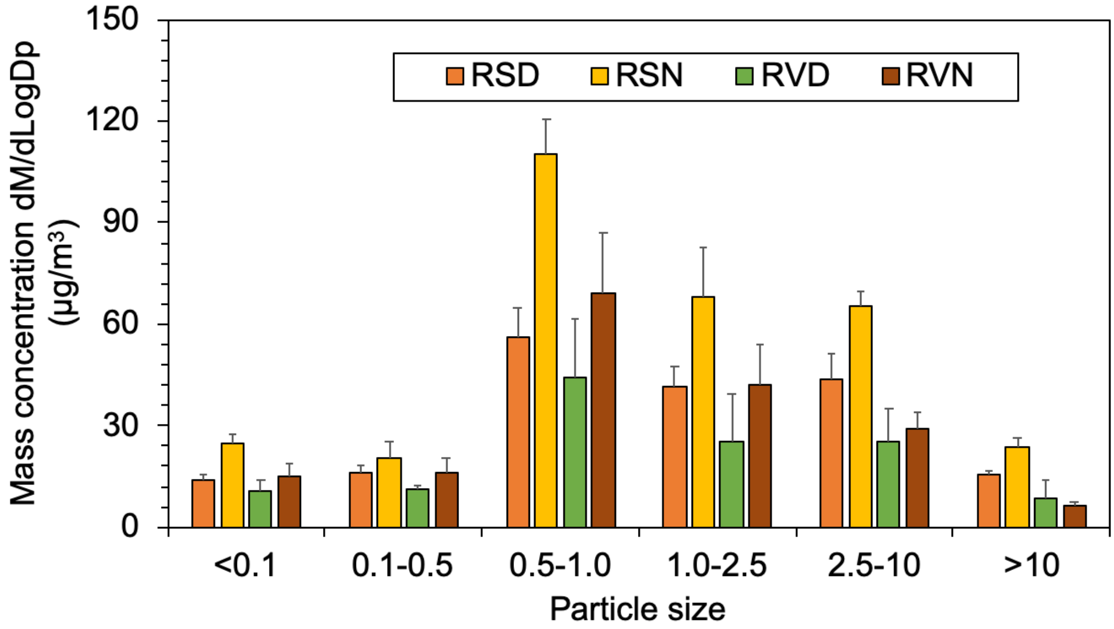

Figure 4.3. Average of mass (dM/dLogDp) concentration of each size PMs in RS and RV at diurnal and nocturnal in Jambi city

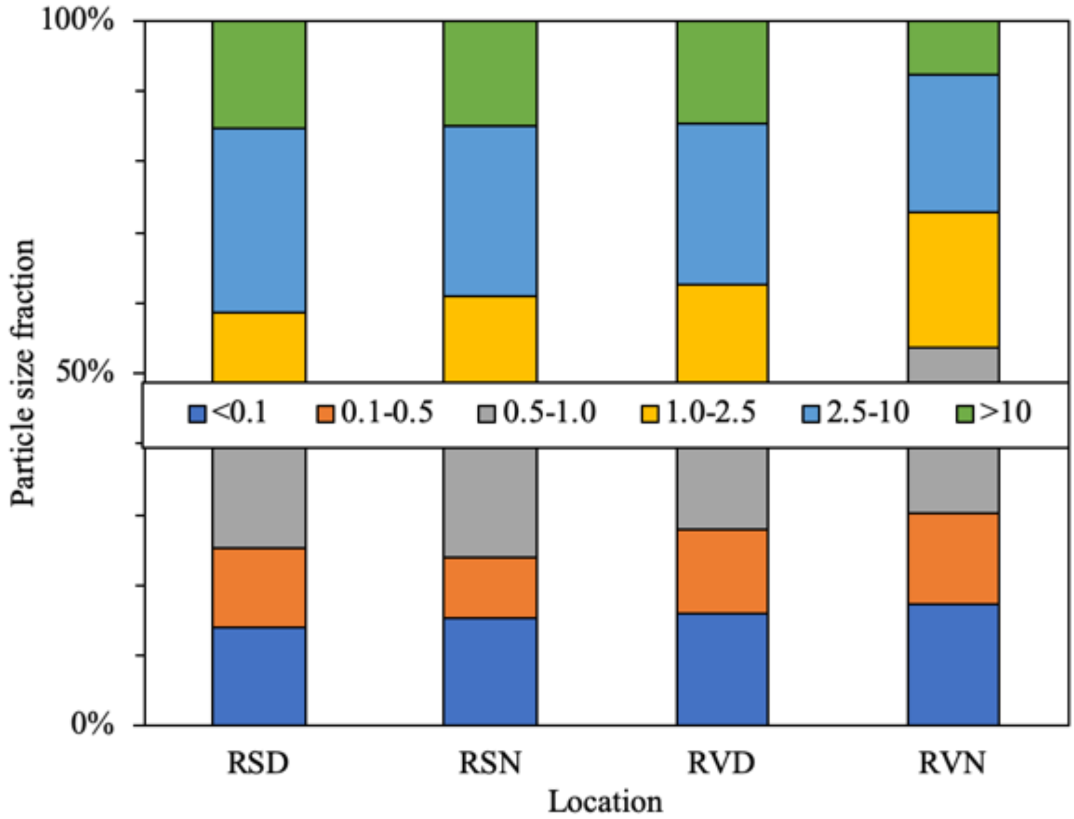

Figure 4.4. Size-segregated particles fraction of the airborne particles in RS and RV at diurnal and nocturnal in Jambi city

Table 4.3. The comparison of $PM_{0.1}$ in Jambi city and other cities in Indonesia and South East Asian (SEA) countries

Location	Site description	Concentration (μg/m³)	Reference
North Sumatera, Indonesia	Urban traffic-day	15.6±6.1	Putri et al., 2021
	Urban traffic-night	10.7±2.0	
	Industry area	16.8±4.0	
	School environment	15.9±1.6	
	Rural-volcano	7.10±2.5	
Bangkok, Thailand	Urban-traffic	7.7	Zhao et al., 2016
Hat Yai, Thailand	Mixed	10.9	
Hanoi, Vietnam	Urban-traffic	6.06-11.9	Thuy et al., 2018
Jambi, Indonesia	Urban traffic-day	14.0±1.6	This study
	Urban traffic-night	24.7±2.9	
	Mixed, riverside-day	10.6±3.1	
	Mixed, riverside-night	15.6±3.8	

Table 4.4. The daily mean, minimum, and maximum of size-segregated PMs in roadside and riverside, Jambi city, Indonesia

Size	Roadside								Riverside							
	Diurnal (μg/m³)			Nocturnal (μg/m³)			Daily (μg/m³)	D/N (-)	Diurnal (μg/m³)			Nocturnal (μg/m³)			Daily (μg/m³)	D/N (-)
	Mean	Min	Max	Mean	Min	Max	Mean	Mean	Mean	Min	Max	Mean	Min	Max	Mean	Mean
<0.1	14.0 ±1.6	11.7	16.2	24.7 ±2.9	21.5	29.2	19.4 ±2.2	0.57 ±0.05	10.6 ±3.1	6.7	14.1	15.2 ±3.8	12.1	22.4	12.9 ±3.4	0.72 ±0.22
0.1-0.5	11.1 ±1.5	9.3	13.4	14.4 ±3.4	10.0	21.3	12.7 ±2.5	0.80 ±0.15	8.0 ±0.5	7.4	8.5	11.3 ±3.0	8.4	16.5	9.7 ±1.8	0.74 ±0.16
0.5-1.0	16.9 ±2.5	14.4	21.8	33.2 ±3.1	28.5	37.0	25.0 ±2.8	0.51 ±0.09	13.4 ±5.2	7.7	19.6	20.9 ±5.3	15.0	31.0	17.1 ±5.2	0.64 ±0.22
1.0-2.5	16.5 ±2.3	13.3	20.4	27.1 ±5.8	18.0	32.4	21.8 ±4.0	0.63 ±0.14	10.0 ±5.6	5.2	20.9	16.7 ±4.8	12.3	25.9	13.3 ±5.2	0.57 ±0.15
2.5-10	26.4 ±4.4	17.7	31.3	39.5 ±2.3	36.0	43.5	32.9 ±3.4	0.67 ±0.09	15.2 ±5.8	9.8	25.3	17.4 ±3.0	14.2	22.6	16.3 ±4.4	0.85 ±0.18
>10	15.2 ±1.4	12.9	17.1	24.0 ±2.8	21.5	28.3	19.6 ±2.1	0.65 ±0.12	9.8 ±5.4	3.3	16.7	6.6 ±1.3	4.6	8.3	8.2 ±3.4	1.48 ±1.17
PM (μg/m³)																
PM0.1	14.0 ±1.6	11.7	16.2	24.7 ±2.9	21.5	29.2	19.4 ±2.2	0.57 ±0.05	10.6 ±3.1	6.7	14.1	15.2 ±3.8	12.1	22.4	12.9 ±3.4	0.72 ±0.22
PM1	42.1 ±3.4	36.3	45.9	72.2 ±8.2	61.0	85.9	57.2 ±5.8	0.59 ±0.06	32.0 ±6.6	24.5	39.7	47.4 ±11.9	35.9	69.8	39.7 ±9.2	0.69 ±0.13
PM2.5	58.6 ±5.3	49.6	64.2	99.3 ±13.2	81.1	118.3	79.0 ±9.2	0.60 ±0.07	42.0 ±11.1	30.4	58.9	64.1 ±16.6	48.2	95.7	53.0 ±13.9	0.66 ±0.11
PM10	85.0 ±8.8	67.3	92.1	138.8 ±13.2	117.1	157.5	111.9 ±11.0	0.61 ±0.06	57.2 ±16.0	40.3	84.2	81.5 ±19.3	62.4	118.3	69.3 ±17.7	0.70 ±0.10
TSP	100.3 ±9.1	82.0	108.5	162.6 ±13.5	141.2	179.1	131.5 ±11.1	0.62 ±0.05	65.9 ±21.2	43.9	100.9	87.8 ±18.9	68.0	122.9	76.8 ±20.1	0.74 ±0.14
$PM_{0.1}$ fraction in TSP (%)																
(This study)	0.17 ±0.02	0.13	0.18	0.18 ±0.01	0.17	0.19	0.17 ±0.01	0.92 ±0.08	0.19 ±0.04	0.12	0.25	0.19 ±0.01	0.17	0.19	0.19 ±0.03	0.97 ±0.24

4.4.2. Location and time period influences on PMs concentration

One of the important factors for the differences of PMs levels taking into account the location and times periods was the amount of traffic. Thus, the correlation between each size range concentration and PMs grouped or $PM_{0.1/1/2.5/10}$ and TSP at RS and RV were performed. The result was shown in **Table 4.5**. All of vehicles types, or MC, LV, HV, and the total vehicles (TV) was shown that they were correlated to the mass concentration of PM in both diurnal and nocturnal times. As seen in the **Table 4.2.**, the percentage of LV among the vehicles types is around 34.4% at diurnal and 29.8% at nocturnal which were found a good relationship with all of particle sizes. As to HV, it was found to be best correlated for particle size around 0.5-1 μm which R^2 value was at 0.45 during night time. Furthermore, coarser particles or >10 μm were mostly influenced by MC. The R^2 value for diurnal and nocturnal was at 0.48 and 0.65, respectively. Such kind of correlation between all vehicle types and PMs mass concentration suggested that the amount of traffic had a positive effect to level of PMs. Even the number of vehicles at the RV was not counted, from the **Figure 4.1**, it is clearly seen that the higher number of vehicles should be found at RS compare to RV which suggested vehicles were more influenced at RS than RV. However, both of them might be influenced by vehicles emission since the RV also located near the street even it was not as busy as HOS. Cokroaminoto street where the RS sites was located.

The Figures **4.3.** and Table **4.4.** illustrated that at both sites, the PMs level was increased from diurnal to nocturnal times. To the contrary, it was not occurred at coarser particles or >10 μm at the RV site during nighttime. The increasing of PMs in RS for TSP was around 162% which the highest increase was at the particle size 0.5-1 μm. Those particle size increased around 96% from diurnal value. However, the increasing of PMs level was in contrast with the traffic amount in where it was decreased at nocturnal times around 53% as the TV. As to the HV, the insignificant decreased was found which was just around ~20%. The higher PMs level at nocturnal could be also affected by meteorological condition particularly due to the decrease of the thickness of mixing layer which reported by many researchers previously **(Pandolfi et al., 2014; Luan et al., 2018)**. The different of the thickness of mixing layer between diurnal and nocturnal could be assumed that only the number of LV that attributed to the level of $PM_{2.5}$. Thus, based on the data in Table **4.4.,** the ratio diurnal to nocturnal of $PM_{2.5}$ was 0.60, while as seen from Table **4.2**., the ratio diurnal/nocturnal for the number of LV was 2.47. Hence, the thickness of mixing layer at diurnal estimated around ~4 times higher than nocturnal which is less than that ratio reported so far **(Du et al., 2013; Pandolfi et al., 2014; Luan et al., 2018)**).

However, other emission sources should be affected to both diurnal and nocturnal, hence, those ratios might be overestimated of the actual values.

Table 4.5. Pearson correlation between the number of each type of vehicles and particle mass concentration (PMC) of each size range and PM category

Vehicles/ PMC	Diurnal				Nocturnal			
	MC	LV	HV	TV	MC	LV	HV	TV
<0.1	-0.31	0.35	-0.42	-0.21	0.10	0.34	-0.09	0.16
0.1-0.5	-0.14	**0.59**	-0.36	0.02	-0.05	0.34	0.33	0.05
0.5-1	0.09	0.28	0.45	0.19	-0.53	-0.28	0.04	-0.51
1-2.5	-0.17	**0.89**	0.25	0.11	0.14	0.48	-0.48	0.21
2.5-10	0.19	0.45	0.28	0.33	-0.09	0.21	0.29	-0.01
>10	0.48	-0.41	0.03	0.34	0.65	0.37	-0.67	0.61
PM0.5	-0.24	0.50	-0.42	-0.11	0.02	0.36	0.14	0.11
PM1	-0.14	0.65	-0.03	0.05	-0.19	0.15	0.12	-0.12
PM2.5	-0.16	0.80	0.09	0.08	-0.05	0.31	-0.14	0.02
PM10	0.00	0.70	0.19	0.21	-0.07	0.35	-0.08	0.02
TSP	0.07	0.62	0.19	0.26	0.07	0.41	-0.22	0.14

Description:
MC : motorcycles
LV : light vehicles
HV : heavy vehicles
TV : total vehicles (MC+LV+HV)

4.4.3. Size-segregated of carbonaceous components

The average carbonaceous component was listed in **Table 4.6.** In Figures **4.6(a-f)** or OC, EC, OC/EC, soot, EC soot-EC/TC and soot-EC/PMC respectively, for each size range in both time period and location were displayed. Furthermore, the percentages of 8-carbonaceous components were shown in **Figure 4.5.** As expected, the EC and soot-EC parameters in UFP were highest among other sizes since it should be related to the vehicle's emission. These values also were higher in the RS compare to RV due to the sampling characteristic. It is confirmed by the peaked of the soot-EC/TC and soot-EC/PMC ratios were found in the UFP. The EC3 fraction which commonly generated from vehicles combustion were found to be the highest in UFP and the RS fraction was larger than RV in both interval times. Among 8~carbon fractions, both OC2 and OC3 shared the highest fraction regardless the location and times period. As to the OC and OC/EC, the peaked value was recorded in size 0.5-1 or 1-2.5 μm, suggested biomass burning more sensitive at this particle sizes **(Phairuang et al., 2019; 2020)**. Such behavior might be correlated with the fraction of pyOC and char-EC as shown in Figure. **4.5** where we found to be the largest in both particle sizes. These concentrations were increased during nocturnal times where RV was higher than RS due to the smaller EC and soot-EC fraction.

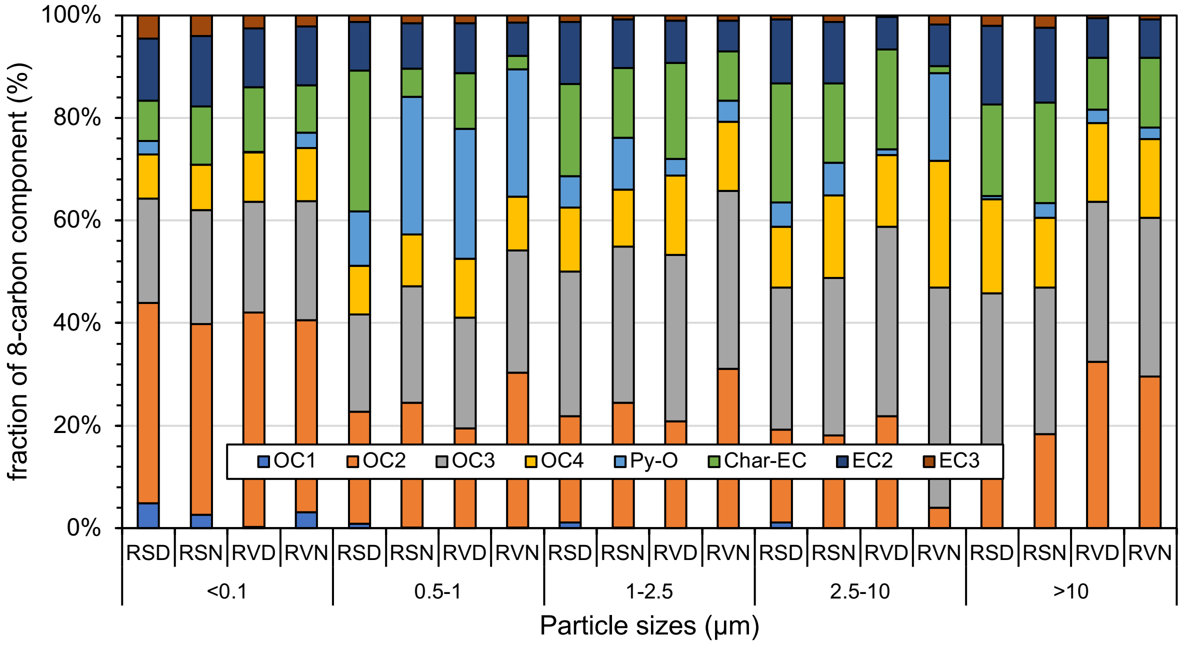

Figure 4.5. Fraction 8-carbonaceous component for both RS and RV at diurnal and nocturnal

As explained previously, one of the important factors affected the mass concentration of size-segregated of PMs was the traffic amount. Reported by **Platt et al., (2017)**, these data also very vital to discuss the carbonaceous behavior in both diurnal and nocturnal. Thus, to evaluate it, the correlation of vehicles counted based on each category and carbonaceous parameters were performed and the data was summarized in Table **4.7**. At diurnal times, a good correlation for both EC and soot-EC in UFP versus HV were found with R^2 value ranged from 0.52-0.82. At nocturnal as well, even it is not as clear as diurnal times, however, the soot-EC/TC ratio correlation with HV number in UFP exhibited the largest R^2 (0.47). In other fine particles i.e. $PM_{1-2.5}$, a good correlation with soot-EC at diurnal times were fairly well with the HV. Taking into account the number of LV, a fairly well correlation with soot-EC in coarser particles were found even those relationship need to be carefully checked. Hence, the degree of correlation depends on the time period and particles sizes, however, the UFP fraction shown a suitable indicator as indices for HV emission pointing the its

Table 4.6. Particle bound-carbonaceous components and their ratio in Jambi city

Sampling site	OC (μg/m³)	EC (μg/m³)	TC (μg/m³)	OC/EC (-)	CharEC (μg/m³)	SootEC (μg/m³)	SootEC /PM (-)	Char/Soot-EC (-)	TC/ PM (-)
					<0.1 μm				
					Diurnal (D) and nocturnal (N)				
RSD	4.71 ±0.83	1.56 ±0.35	6.25 ±0.82	3.27 ±1.15	0.49 ±0.27	1.04 ±0.17	0.08 ±0.02	0.48 ±0.25	0.45 ±0.07
RSN	4.64 ±1.31	1.90 ±0.34	6.54 ±1.58	2.43 ±0.47	0.74± 0.21	1.16 ±0.23	0.05 ±0.01	0.65 ±0.20	0.26 ±0.05
RVD	3.61 ±0.34	1.31 ±0.20	4.91 ±0.48	2.81 ±0.41	0.62 ±0.11	0.69 ±0.11	0.07 ±0.03	0.90 ±0.10	0.51 ±0.20
RVN	6.41 ±2.10	1.90 ±0.24	8.31 ±2.30	3.32 ±0.74	0.77 ±0.09	1.13 ±0.24	0.08 ±0.01	0.71 ±0.17	0.54 ±0.04
					Daily				
RS	4.68 ±1.07	1.72 ±0.34	6.39 ±1.20	2.85 ±0.81	0.62 ±0.24	1.10 ±0.20	0.06 ±0.02	0.56 ±0.23	0.36 ±0.06
RV	5.01 ±1.22	1.60 ±0.22	6.61 ±1.39	3.06 ±0.57	0.70 ±0.10	0.91 ±0.17	0.07 ±0.01	0.81 ±0.14	0.53 ±0.12
					0.5-1 μm				
					Diurnal (D) and nocturnal (N)				
RSD	4.56 ±1.07	2.82 ±1.74	7.38 ±2.71	1.90 ±0.68	2.03 ±1.39	0.79 ±0.38	0.05 ±0.03	2.48 ±0.93	0.45 ±0.20
RSN	8.38 ±2.67	1.58 ±0.38	9.96 ±2.60	5.66 ±2.52	0.66 ±0.31	1.03 ±0.23	0.03 ±0.01	0.57 ±0.39	0.30 ±0.06
RVD	6.28 ±4.48	1.81 ±1.27	8.09 ±4.97	5.46 ±4.40	0.89 ±1.12	0.92 ±0.62	0.07 ±0.04	1.22 ±1.69	0.62 ±0.27
RVN	8.30 ±3.50	0.98 ±0.61	9.27 ±3.87	7.67 ±2.57	0.24 ±0.61	0.73 ±0.26	0.04 ±0.01	0.49 ±1.36	0.43 ±0.06
					Daily				
RS	6.47 ±1.87	2.20 ±1.06	8.67 ±2.66	3.78 ±1.60	1.35 ±0.85	0.91 ±0.30	0.04 ±0.02	1.52 ±0.66	0.37 ±0.13
RV	7.29 ±3.99	1.39 ±0.94	8.68 ±4.42	6.57 ±3.48	0.57 ±0.87	0.83 ±0.44	0.05 ±0.02	0.86 ±1.52	0.52 ±0.17
					1-2.5 μm				
					Diurnal (D) and nocturnal (N)				
RSD	4.21 ±2.46	1.92 ±1.69	6.13 ±4.01	2.99 ±2.19	1.10 ±0.96	0.82 ±0.76	0.05 ±0.05	1.40 ±0.71	0.38 ±0.27
RSN	6.53 ±3.23	2.04 ±0.84	8.57 ±3.34	3.88 ±3.19	1.16 ±0.67	0.88 ±0.46	0.04 ±0.03	1.57 ±1.01	0.33 ±0.19
RVD	2.73 ±0.91	1.11 ±0.58	3.84 ±1.34	3.58 ±3.62	0.74 ±0.43	0.37 ±0.18	0.05 ±0.04	2.01 ±1.04	0.51 ±0.36
RVN	9.75 ±4.89	1.95 ±1.43	11.70 ±5.96	5.95 ±3.48	1.13 ±0.99	0.82 ±0.55	0.05 ±0.05	1.56 ±1.03	0.75 ±0.51
					Daily				
RS	5.37 ±2.85	1.98 ±1.27	7.35 ±3.67	3.43 ±2.69	1.13 ±0.82	0.85 ±0.61	0.04 ±0.04	1.49 ±0.86	0.36 ±0.23
RV	6.24 ±2.90	1.53 ±1.00	7.77 ±3.65	4.77 ±3.55	0.93 ±0.71	0.59 ±0.36	0.05 ±0.04	1.79 ±1.03	0.63 ±0.44
					2.5-10 μm				
					Diurnal (D) and nocturnal (N)				
RSD	2.75	1.58	4.33	1.81	1.01	0.57	0.02	1.79	0.17

	±0.73	±0.32	±0.73	±0.63	±0.31	±0.07	±0.00	±0.57	±0.03
RSN	9.69 ±11.4	3.95 ±4.47	13.6 ±15.8	2.80 ±1.57	2.13 ±2.48	1.82 ±2.11	0.02 ±0.02	1.33 ±0.84	0.35 ±0.41
RVD	1.72 ±0.57	0.65 ±0.17	2.37 ±0.73	2.64 ±0.40	0.48 ±0.12	0.17 ±0.06	0.01 ±0.00	3.21 ±1.08	0.17 ±0.05
RVN	3.39 ±1.37	0.82 ±0.29	4.21 ±1.14	5.23 ±4.54	0.58 ±0.33	0.24 ±0.06	0.01 ±0.01	2.74 ±2.01	0.20 ±0.10
Daily									
RS	6.22 ±6.08	2.76 ±2.39	8.98 ±8.25	2.31 ±1.10	1.57 ±1.40	1.20 ±1.09	0.02 ±0.01	1.56 ±0.70	0.26 ±0.22
RV	2.55 ±0.97	0.73 ±0.23	3.29 ±0.94	3.94 ±2.47	0.53 ±0.22	0.20 ±0.06	0.01 ±0.00	2.98 ±1.54	0.18 ±0.07
>10 μm									
Diurnal (D) and nocturnal (N)									
RSD	1.54 ±1.93	0.84 ±0.99	2.38 ±2.91	1.77 ±0.24	0.43 ±0.40	0.42 ±0.59	0.03 ±0.04	1.35 ±0.39	0.15 ±0.17
RSN	1.34 ±0.69	0.79 ±0.47	2.13 ±1.14	1.95 ±1.02	0.42 ±0.28	0.37 ±0.20	0.02 ±0.01	1.10 ±0.47	0.09 ±0.05
RVD	0.86 ±1.50	0.21 ±0.42	1.06 ±1.90	5.23 ±3.60	0.11 ±0.30	0.09 ±0.13	0.01 ±0.01	1.15 ±0.89	0.14 ±0.13
RVN	0.92 ±0.59	0.26 ±0.23	1.17 ±0.81	9.70 ±14.6	0.16 ±0.16	0.10 ±0.08	0.01 ±0.01	1.44 ±1.28	0.18 ±0.10
Daily									
RS	1.44 ±1.31	0.82 ±0.73	2.26 ±2.03	1.86 ±0.63	0.42 ±0.34	0.39 ±0.40	0.02 ±0.03	1.23 ±0.43	0.12 ±0.11
RV	0.89 ±1.04	0.23 ±0.33	1.12 ±1.36	7.47 ±9.09	0.14 ±0.23	0.10 ±0.10	0.01 ±0.01	1.29 ±1.09	0.16 ±0.11

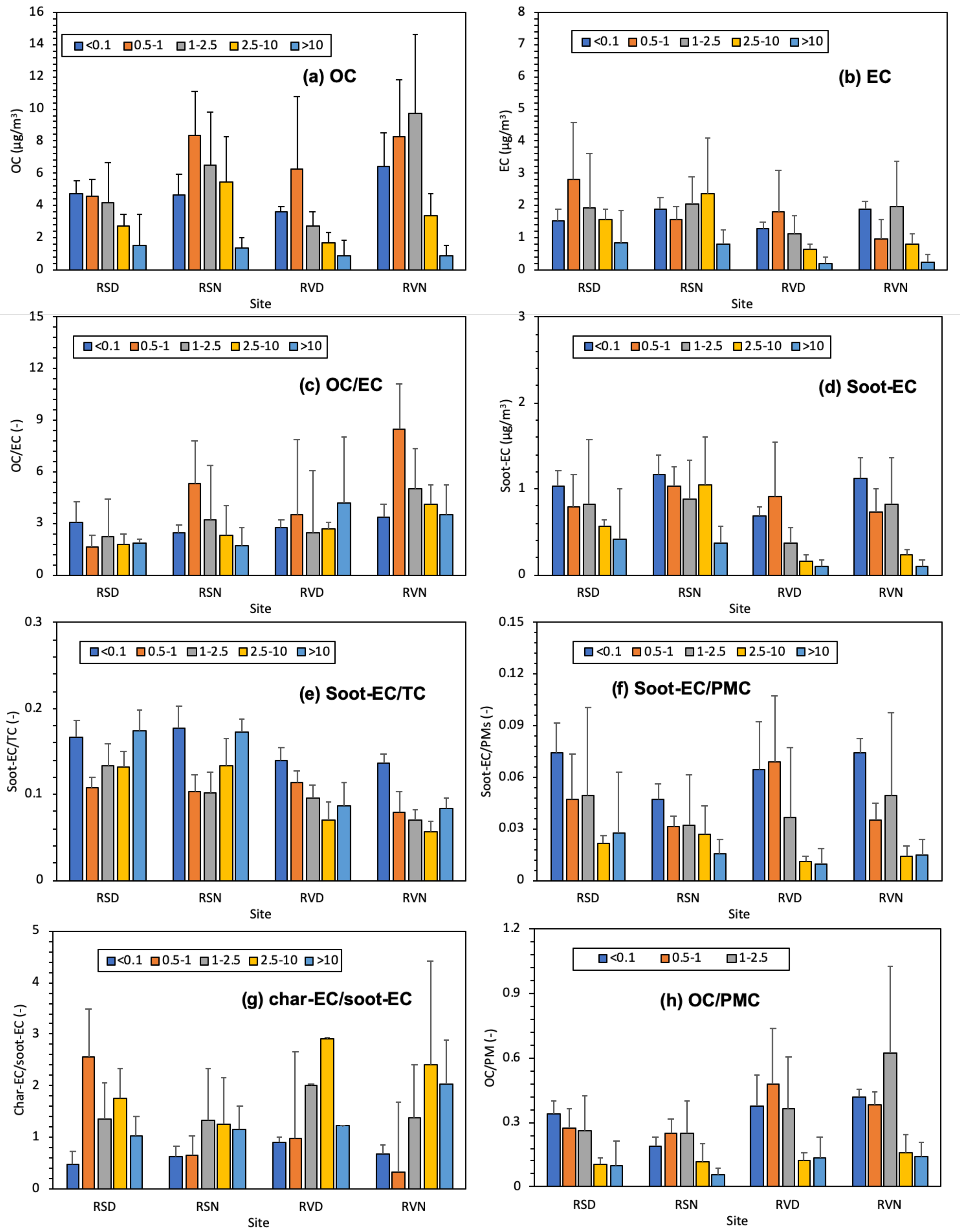

Figure 4.6. Carbonaceous component and their ratios in RS and RV at diurnal and nocturnal in Jambi city (a) OC (b) EC (c) OC/EC (d) soot-EC (e) soot-EC/TC (f) soot-EC/PMC (g) char-EC/soot-EC (h) OC/PMC

Table 4.7. Pearson correlation between types of vehicles, mass of PMs, and their carbonaceous component at diurnal and nocturnal

Parameters	Diurnal				Nocturnal			
	<0.1 μm							
	MC	LV	HV	TV	MC	LV	HV	TV
OC	-0.56	-0.41	-0.28	-0.68	-0.18	0.07	-0.55	-0.16
EC	0.47	0.24	**0.82**	**0.57**	-0.17	-0.24	-0.12	-0.21
OC/EC	-0.70	-0.38	-0.81	-0.83	-0.06	0.40	-0.74	0.01
soot-EC	-0.06	-0.21	**0.52**	-0.09	-0.46	-0.41	-0.34	-0.49
soot-EC/TC	0.35	0.03	**0.70**	0.38	-0.43	-0.78	0.47	-0.53
soot-EC/PMC	0.14	-0.34	**0.53**	0.07	-0.54	-0.60	-0.24	-0.61
Parameters	0.5-1 μm							
	MC	LV	HV	TV	MC	LV	HV	TV
OC	0.08	-0.37	0.15	-0.02	-0.24	-0.04	-0.31	-0.22
EC	0.35	-0.32	0.17	0.25	-0.52	-0.49	0.22	-0.54
OC/EC	-0.48	0.18	-0.07	-0.42	0.10	0.13	-0.35	0.10
soot-EC	0.23	-0.40	0.19	0.12	-0.30	-0.34	-0.18	-0.34
soot-EC/TC	0.13	-0.41	0.23	0.02	0.09	-0.31	0.22	0.02
soot-EC/PMC	0.21	-0.44	0.08	0.08	-0.11	-0.28	-0.19	-0.17
Parameters	1-2.5 μm							
	MC	LV	HV	TV	MC	LV	HV	TV
OC	-0.40	-0.38	-0.16	-0.51	-0.51	-0.49	0.09	-0.54
EC	-0.44	-0.58	-0.22	-0.61	-0.51	-0.23	0.83	-0.45
OC/EC	0.25	0.48	0.19	0.39	-0.05	-0.21	-0.41	-0.10
soot-EC	-0.45	-0.50	-0.16	-0.59	-0.56	-0.56	**0.60**	-0.57
soot-EC/TC	-0.23	-0.53	0.11	-0.37	0.03	-0.22	**0.61**	0.00
soot-EC/PMC	-0.43	-0.55	-0.18	-0.59	-0.50	-0.56	**0.66**	-0.52
Parameters	2.5-10 μm							
	MC	LV	HV	TV	MC	LV	HV	TV
OC	0.43	0.05	0.14	0.44	-0.66	-0.09	-0.13	-0.58
EC	0.23	0.48	0.28	0.38	-0.54	0.04	-0.11	-0.45
OC/EC	0.18	-0.25	-0.03	0.10	-0.46	-0.42	0.19	-0.47
soot-EC	0.39	-0.31	0.35	0.30	-0.66	-0.09	-0.06	-0.58
soot-EC/TC	-0.24	-0.63	-0.02	-0.42	-0.26	-0.27	0.62	-0.26
soot-EC/PMC	0.12	-0.61	0.00	-0.07	-0.65	-0.08	-0.08	-0.57
Parameters	>10 μm							
	MC	LV	HV	TV	MC	LV	HV	TV
OC	0.33	0.16	0.43	0.39	0.21	**0.74**	-0.24	0.34
EC	0.33	0.17	0.40	0.39	0.34	**0.78**	-0.54	0.45
OC/EC	0.09	-0.19	0.48	0.06	-0.47	-0.38	0.73	-0.46
soot-EC	0.31	0.15	0.40	0.36	0.30	0.76	-0.44	0.41
soot-EC/TC	0.05	-0.32	-0.02	-0.04	0.08	-0.18	-0.22	0.02
soot-EC/PMC	0.30	0.16	0.40	0.36	0.10	0.65	-0.32	0.22

Description:
MC : motorcycles
LV : light vehicles
HV : heavy vehicles
TV : total vehicles (MC+LV+HV)
PMC : mass concentration
N/A : not analyses

4.4.4. Influenced of open biomass burning at diurnal and nocturnal periods

In Jambi, one of the possible sources affected to size-segregated PMs including UFP is biomass burning since it was surrounded by peatland fires that commonly occurs annually during dry season. To evaluated it, the maps of hotspot as indicator of biomass burning and air mass trajectory was displayed in **Figure 4.7**. As shown, many of hotspots were distributed in Sumatra Island, especially in the southern part of Jambi city where the sampling taking placed. Since the backward air mass trajectory mostly coming from these parts, the number of hotspots was counted only in the southern area of Jambi city that used for the correlation between PMs and the hotspots number as listed in **Table 4.8.** The moderate correlation between hotspots and PMC was found in the RS at the UFP and 0.1-0.5 μm particle size. However, the long-ranged transportation influenced could not be concluded as the factors since other sizes of PMs were shown insignificance correlation with the number of hotspots. In addition, in the RV, regardless the particles size, no correlation was found. One of the possible reasons for such kind of result due to the short term of sampling period compared to previous report that found a good relationship between the number of hotspots with $PM_{2.5}$, PM_{10} and TSP **(Anwar et al., 2010; Kusumaningtyas and Aldrian, 2013)** . This study was performed for two weeks that might the satellite could not detect the whole of hotspot especially local and smaller spots.

Reported by **Putri et al., (2021),** a correlation between OC/EC and EC could be one of the alternatives to discuss the possible influence of local and transboundary biomass burning in Jambi city. UFP is well-known as fresh emission both from vehicles and biomass burning while $PM_{0.5\text{-}1}$ reported by **Jamhari et al., (2021)** was very sensitive to the biomass burning especially affected by peatland fires in Sumatra Island. As previously discussed in the **section 4.4.3.** the highest of OC and OC/EC ratio was found in this particle sizes. Thus, a correlation between OC/EC versus EC was plotted for both particles sizes as illustrated in **Figure 4.7.** For the evaluation, the same data from several urban location in the Asian countries were plotted at the same figure **(Thuy et al., 2018; Phairuang et al., 2019; Kim et al., 2011a; 2011b; Kim et al., 2016).** Furthermore, data reference which represent the influence of fresh biomass burning at UFP sampled in the peatland fire sites were plotted together to evaluate whether the current study as same as correlation in urban area or tends to move to the peatland fires correlation. In **Figure 4.7.** the dash line is represented the correlation in urban area which might be corresponding to the dominant influence of fossil fuel burning from vehicles emission, while in the upper-right side is a location for peatland fires.

Based on **Figure 4.7.**, for the UFP, regardless the location and time periods, the correlation was mostly located at the dash line which some of the data move to the upper sites. It was indicated a slight influence from biomass burning to UFP might be occurs. For the $PM_{0.5-1}$ fractions at the diurnal time in RS, the correlation was comparable with the UFP correlation while the remain correlation at the RS for nocturnal and at RV for diurnal and nocturnal, the values were largely shifted to the biomass burning side. Even the effect for such behavior is not clear at this time, local biomass burning especially local peatland fires might be caused such kind of trends. To confirm it, further investigations on other chemical components that correlated with peatland fire should be added. Nonetheless, the correlation between OC/EC and EC for these particle sizes may provide a useful perspective on the biomass and vehicles influences.

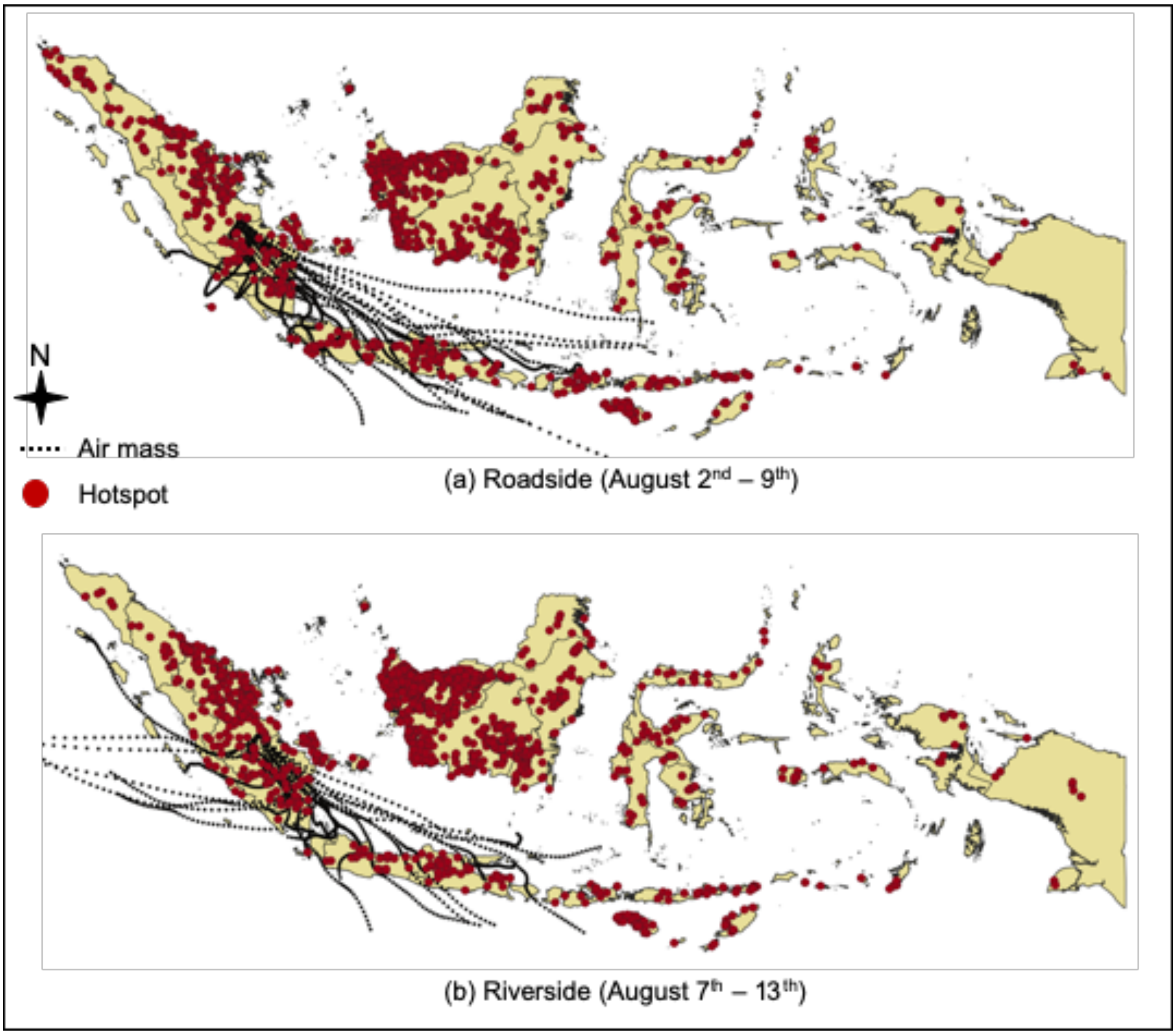

Figure 4.7. Maps of hotspot and air mass trajectories during sampling time in Jambi city, Indonesia (a) roadside (August 2^{nd}-9^{th}) and (b) riverside (August 7^{th}-13^{th})

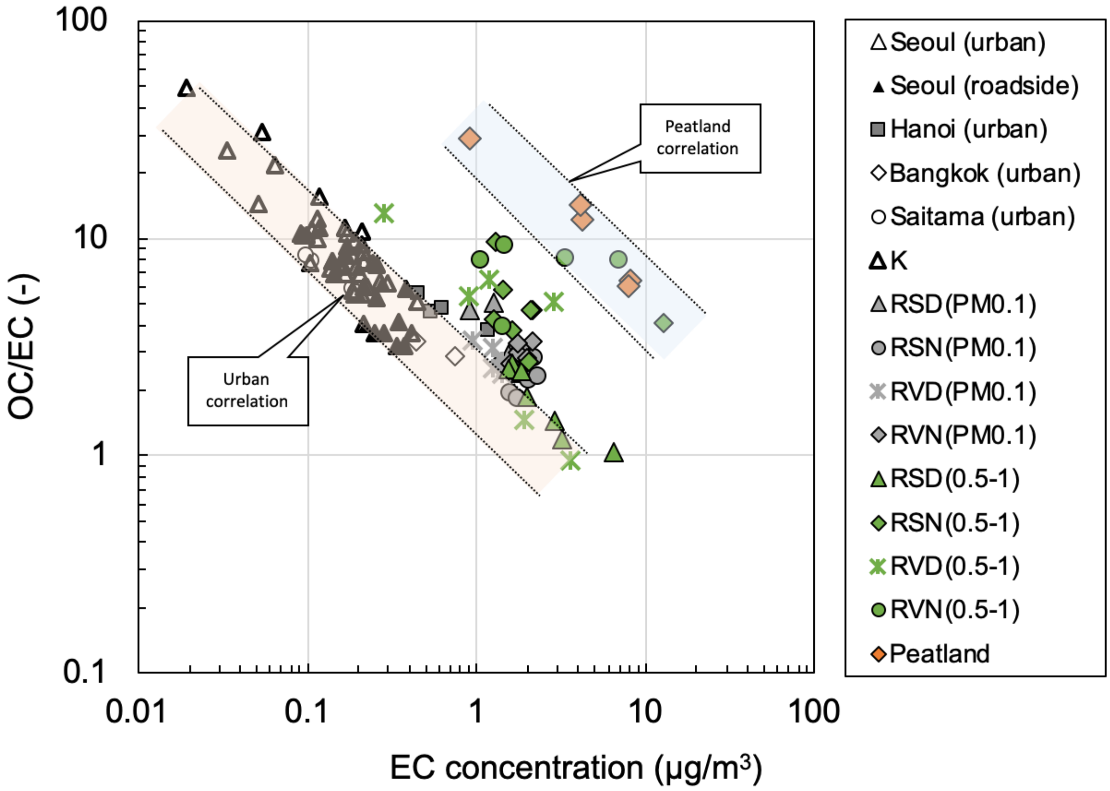

Figure 4.8. OC/EC vs EC in RS and RV and urban sites in several Asian countries

Table 4.8. Pearson correlation between the daily number of hotspots in southern part of Sumatera Island with daily mass of PMs, and their carbonaceous component at RS and RV sites

Particle size	Location	
<0.1	**RS**	**RV**
PMC	0.66	-0.46
OC	-0.12	-0.28
EC	0.32	-0.11
OC/EC	-0.33	-0.23
0.1-0.5	**RS**	**RV**
PMC	**0.77**	-0.28
OC	N/A	N/A
EC	N/A	N/A
OC/EC	N/A	N/A
0.5-1	**RS**	**RV**
PMC	0.29	-0.42
OC	-0.11	-0.73
EC	0.06	-0.34
OC/EC	-0.08	-0.58
1-2.5	**RS**	**RV**
PMC	0.37	-0.28
OC	-0.11	-0.62
EC	-0.24	-0.16
OC/EC	0.40	-0.24

2.5-10	RS	RV
PMC	0.03	-0.25
OC	-0.07	-0.25
EC	0.06	0.52
OC/EC	-0.06	-0.36
>10	**RS**	**RV**
PMC	0.08	-0.46
OC	0.00	-0.37
EC	-0.10	-0.48
OC/EC	0.11	0.18

4.5. Conclusion

To evaluate the diurnal and nocturnal periods of size-segregated of PMs including UFP, the air sampling for 12 h was performed in a roadside and a riverside of Jambi city, Sumatra Island, Indonesia. The status, characteristics, and behavior of PMs were evaluated based on the carbonaceous component togethers with the distribution of hotspot and backward air mass trajectory arrived at the sampling sites. These data were also discussed to specify both local and transboundary influenced to both sampling sites. As to the PMs level, PM2.5 and PM10 were exceed the limitation standard proposed by WHO. It was also higher than NAAQS of Indonesia except PM2.5 at the riverside. In the RS, the number of HV have a good relationship with particles size at 0.5-1 µm at nocturnal times while the MC seem to be most affected on the coarse fraction (>10 µm) in both interval times, indicated a positive influence of traffic to the PMs level. The EC and soot-EC in the UFP were confirmed to be the high effect from HV. Based on OC/EC versus EC correlation, 0.5-1 µm particle sizes at nocturnal time was influenced by local biomass burning. A slight influence of transboundary biomass burning was found at UFP. However, in term of this influenced, the particles size 0.5-1 µm was more sensitive since it largely shifted from “urban” to “biomass burning” correlation. Hence, the used of OC/EC vs EC correlation can be useful for the evaluation of emission sources of size-segregated of PMs such as traffic and biomass burning. Nonetheless, other chemicals information is needed for the detail evaluation of emission sources in both diurnal and nocturnal in the future studies.

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Chapter V

Rainy and dry season of size-segregated PMs including UFP in Indonesia

5.1. Objectives of the study

The further studies to evaluate the status, characteristic, and sources of size-segregated of PMs including UFPs in Indonesia, the seasonal different between rainy and dry season were examined in Indonesia. Carbonaceous components in both seasons were evaluated to discuss the different behavior of both seasons. The distribution of hotspot and backward air mass trajectory arrived at the sampling site were used to discuss the characteristic of PMs and carbon components in both rainy and dry seasons.

5.2. Sampling sites

To discuss the effect of season to the size-segregated of PMs including UFP, the sampling sites were selected at three different characteristic cities in Sumatra Island, Indonesia. The reason of the selected study was regarding the possible local emission sources such as vehicles emission and biomass burning particularly peatland fires during dry season that commonly occur on Sumatra Island. Although the distance between one site and other sites varied from 184.86 to 354.28 km, however, the meteorological condition in all sites was similar that made the comparison reasonable among the sites. The detail location of sampling site was displayed in **Figure 5.1.** and the backward air mass trajectory at both seasons was displayed in **Figure.5.2.** Then, more detail explanation of each sampling site was discussed below and the sampling duration, period, and meteorological conditions in Sumatra Island were listed in **Table 5.1.**

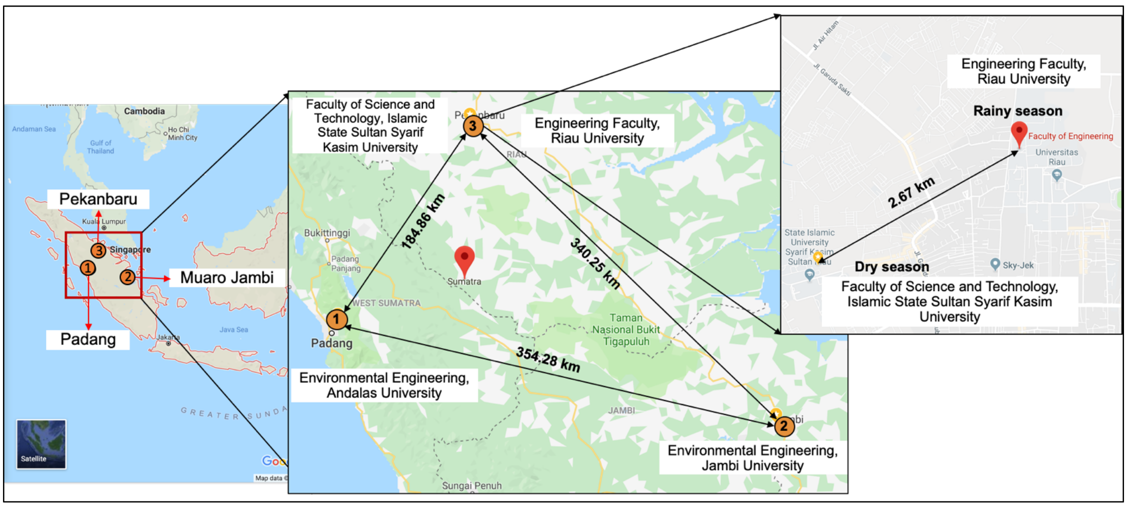


Figure 5.1. Locations of sampling sites in three different cities on Sumatra Island, Indonesia

Table 5.1. Sampling period, duration and meteorological condition in Sumatra Island, Indonesia in 2018

Location	Season	Date	Sample (n)	Temperature (°C)	Humidity (%)	Precipitation (mm)	Sunlight (hour)	Wind direction
Padang	Rainy	March 08th-13th	5	26.53 ±0.76	89.00 ±4.04	11.2 ±17.95	5.13 ±2.13	N
	Dry	August 17th-29th	8	26.92 ±0.92	75.46 ±5.71	7.5 ±4.94	6.01 ±3.84	N
Jambi	Rainy	March 14th-19th	5	27.35 ±0.75	83.00 ±4.10	4.1 ±6.22	5.32 ±2.73	N, NE
	Dry	August 17th-24th	8	27.80 ±0.85	78.00 ±4.44	0.4 ±1.06	6.84 ±2.04	SE
Pekanbaru	Rainy	March 20th-25th	5	27.28 ±0.83	80.33 ±5.99	10.0 ±17.55	5.72 ±2.91	N
	Dry	August 17th-26th	8	27.86 ±0.94	78.30 ±4.95	1.8 ±4.72	4.46 ±2.18	S, N

Sources: www.bmkg.go.id

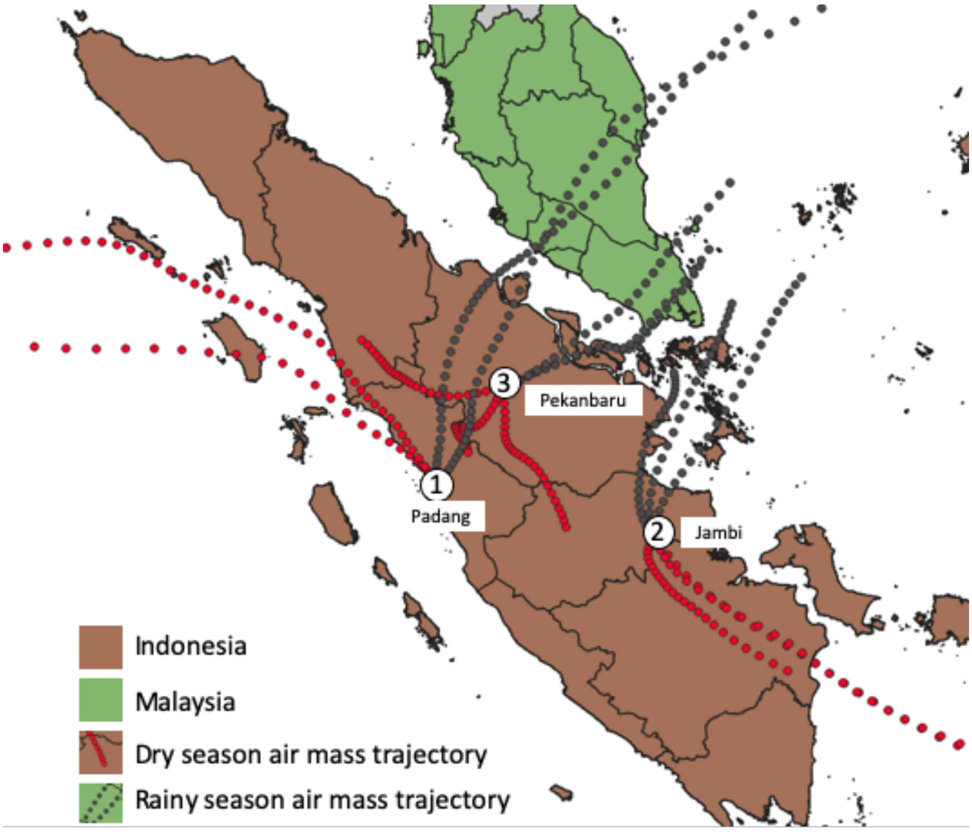


Figure 5.2. Air mass trajectory during rainy and dry season in all sampling site, in Sumatra Island

5.2.1. Padang city

The first sampling sites was located in Padang city at the roof top of the Environmental Engineering (4^{th} floor) building, Engineering faculty, Andalas University, Padang city. It is located at 00º 54’ 46.3” in the South and 100º 27’ 50.0” in the East. As to the land use, the site was surrounded by green-belt forest which is around 13 km from the central of the city. In the south of sampling site, there is a large cement factory around 2.5 km that commonly uses coal as a main fuel **(Bachtiar et al., 2016).** Padang city`s climatology is classified as tropical rain forest. Throughout the year, rainfall is commonly occurring. Hence, Padang city is one of the wettest regions in Indonesia **(BPS Padang city, 2018).**

5.2.2. Muaro Jambi regency

The second sampling site was located at the Jambi University, i.e. in the rooftop of 3^{rd} floor of the Environmental Engineering building. It is situated at 01°40.437′ in the South and 103°34.566′ in the East around 48 m a.s.l. Jambi University is located at the border of two subdistrict or Mestong and the Jambi Luar Kota, in Muaro Jambi regency which located at the east coast of Sumatra Island **(BPS Muaro Jambi, 2018).** In Muaro Jambi, the land is uses for agriculture, residential, and industrial areas. Nearby sampling sites, there is a cross-provincial road between Jambi and South Sumatra Province. As similar with Padang city, Jambi city climate also categorized as rain forest climate but is not as wet as Padang city with a smaller number of rainy days than Padang city.

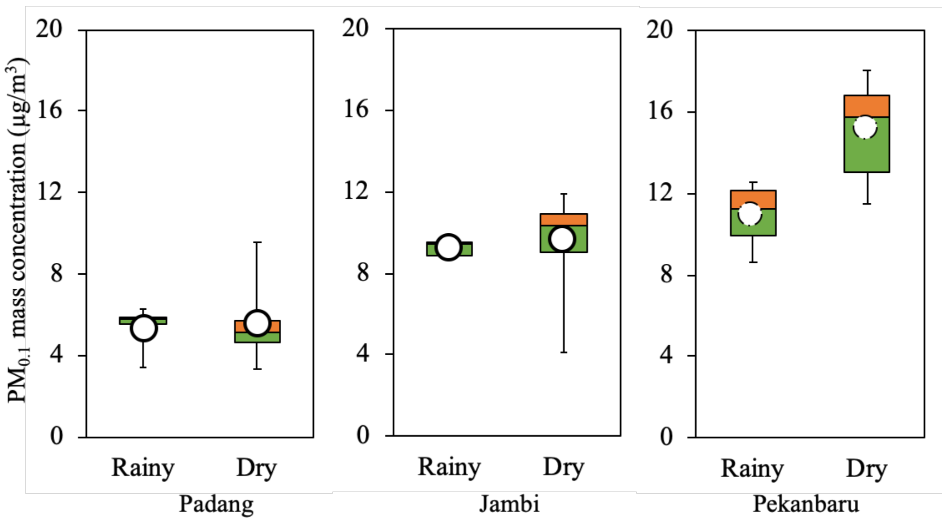
5.2.3. Pekanbaru city

The thirds location to evaluate the seasonal different of PMs including UFP in Indonesia was located in the Pekanbaru city, Riau Province i.e. During rainy season, the sampling was located at the Engineering building faculty of Riau University, situated at 00º 28’ 47.8” in the North and 101º 22’ 35.9” in the East around 69 m a.s.l **(BPS Pekanbaru city, 2018)**. In dry season, the sampling site was move around 2 km from Riau University i.e. in the Science and Technology faculty of Sultan Syarif Kasim State Islamic University which located at 00º 28’ 4.6” in the North and 101º 21’ 22.1” in the East. Both sampling sites were similar surrounded by housing, hospitals, roads, restaurants and also cross-provincial roads that connect the Riau province and West Sumatra province.

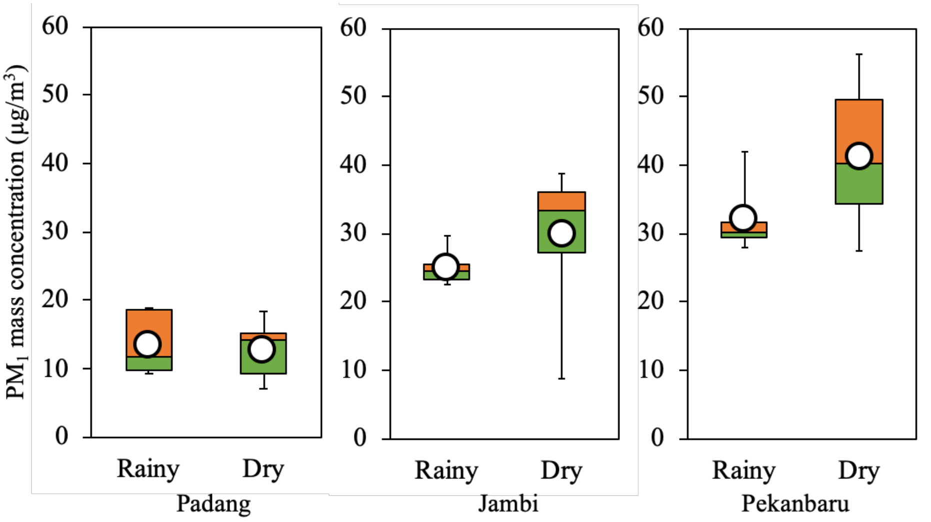
5.3. Result and discussion

5.3.1. Rainy and dry season PMs mass concentration

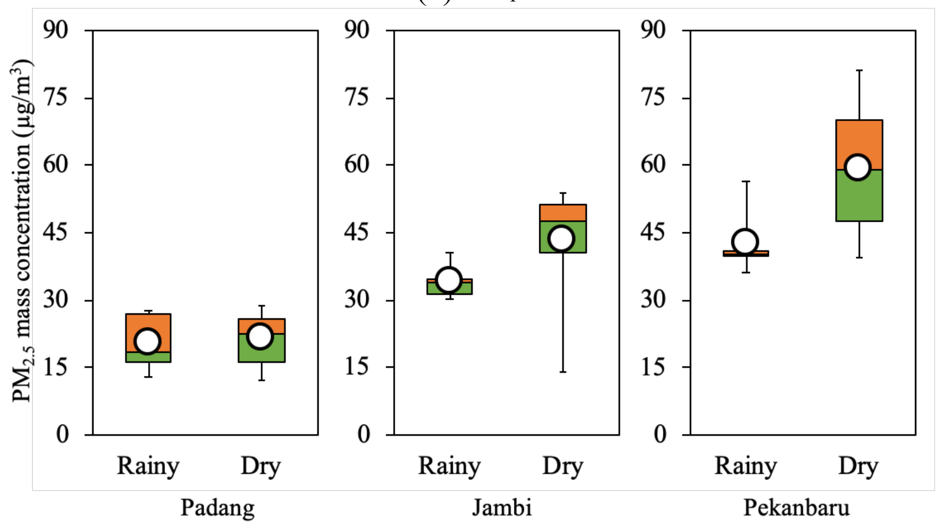
The **Figure 5.3.** shown the average grouped PMs mass concentration or $PM_{0.1}$, PM_1, $PM_{2.5}$, $PM_{10,}$ and TSP, respectively in all sites in both rainy and dry seasons. In Pekanbaru, both rainy and dry season, the $PM_{2.5}$ and PM_{10} levels were exceeded the WHO guidelines for 24 hours. In Jambi, only the PM_{10} during rainy season was less than that guidelines while in Padang sites, regardless the season, the $PM_{2.5}$ and PM10 were lowest than the guidelines values. Taking into account the UFP level, the rainy-dry season level at Jambi and Pekanbaru was ranged from 9.2 – 9.6 and 10.9 – 15.6 µg/m^3, respectively. It was comparable with the value recorded in Bangkok, Thailand (14.80±1.99 µg/m^3) **(Phairuang et al., 2019)** and two times higher than that value founded in Padang site (5.36 and 5.57 µg/m3 in rainy and dry season, respectively). Compare to local city in Japan, the level of UFP in Indonesia was much larger (2.7 µg/m^3) **(Zhao et al., 2016).**



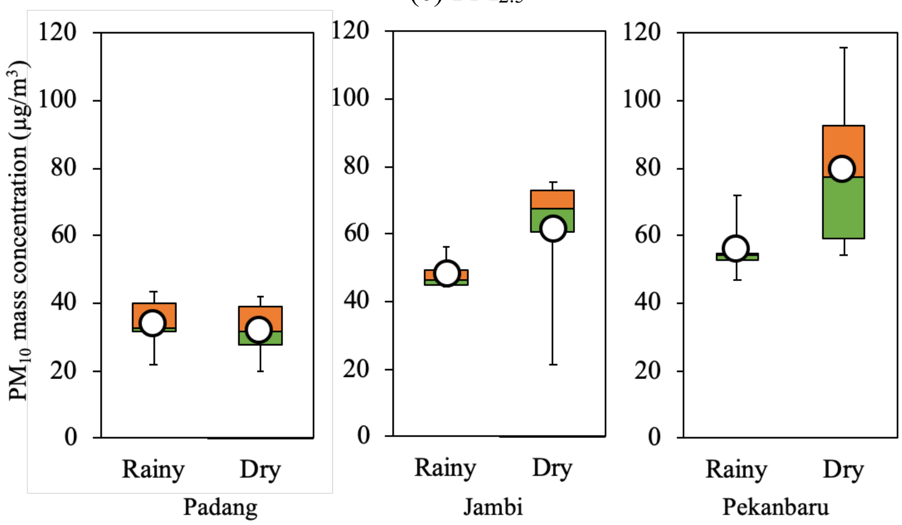
(a) $PM_{0.1}$



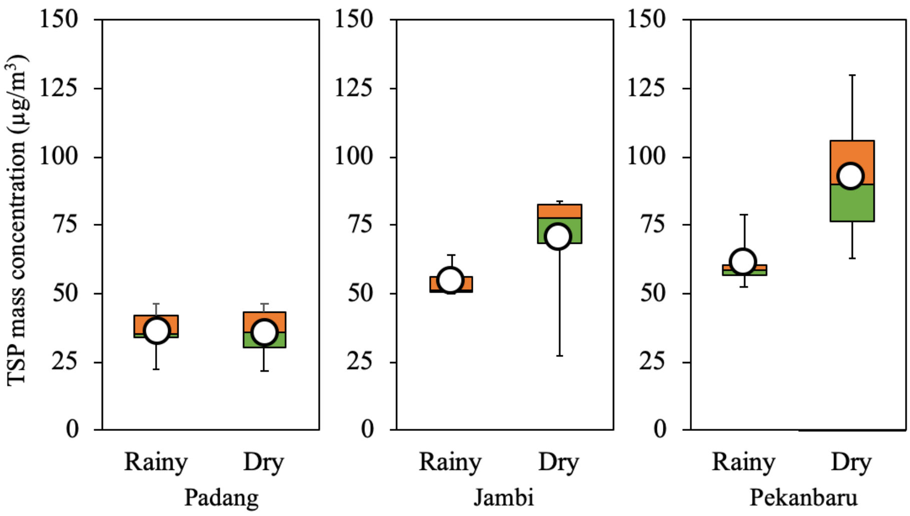
(b) PM_1



(c) $PM_{2.5}$



(d) PM_{10}



(e) TSP

Figure 5.3. Seasonal particle mass concentration in Sumatra Island, Indonesia: (a) $PM_{0.1}$, (b) PM_1, (c) $PM_{2.5}$, (d) PM_{10} and (e) TSP.

As explained previously, one of the expected sources of PMs during dry season in Indonesia was from forest fires in the peatland area which emitted a large amount of smoke haze. In the present study, the PMs levels for the dry season were much smaller than the levels reported during the previous haze episodes. Previously, in the dry season 2012, the $PM_{2.5}$ levels were reported reached 7812 µg/m^3 in central Kalimantan **(Betha et al., 2013).** Then, in Riau provinces 2013, the PM_{10} levels ranged from 300-600 µg/m^3 **(Kusumaningtyas and Aldrian, 2016)**. It is comparable with the situation in 2015 where the PM_{10} in Pekanbaru city was 600 µg/m^3 **(Crippa et al., 2016).** The significantly decreased taking into account the PMs level could be reasonable since the number of hotspots were drastically declined since 2018 **(Aminingrum, 2017; Jikalahari, 2018; Saputra, 2019**) as seen from **Figure 5.4.** The higher hotspots were recorded from May until September or October, then, it will decrease due to the beginning of rainy season. The PM_{10} in the recent study was 7~times lower than that value recorded in 2015, being reasonable since the number of hotspots recorded in Sumatra Island was 6~times higher in September 2015 (2672) than in August 2018 (424) when this study was performed. Hence, the hotspot number was correlated to the PMs level as reported so far **(Anwar et al., 2010; Gaveau et al., 2014; Kusumaningtyas and Aldrian, 2016).**

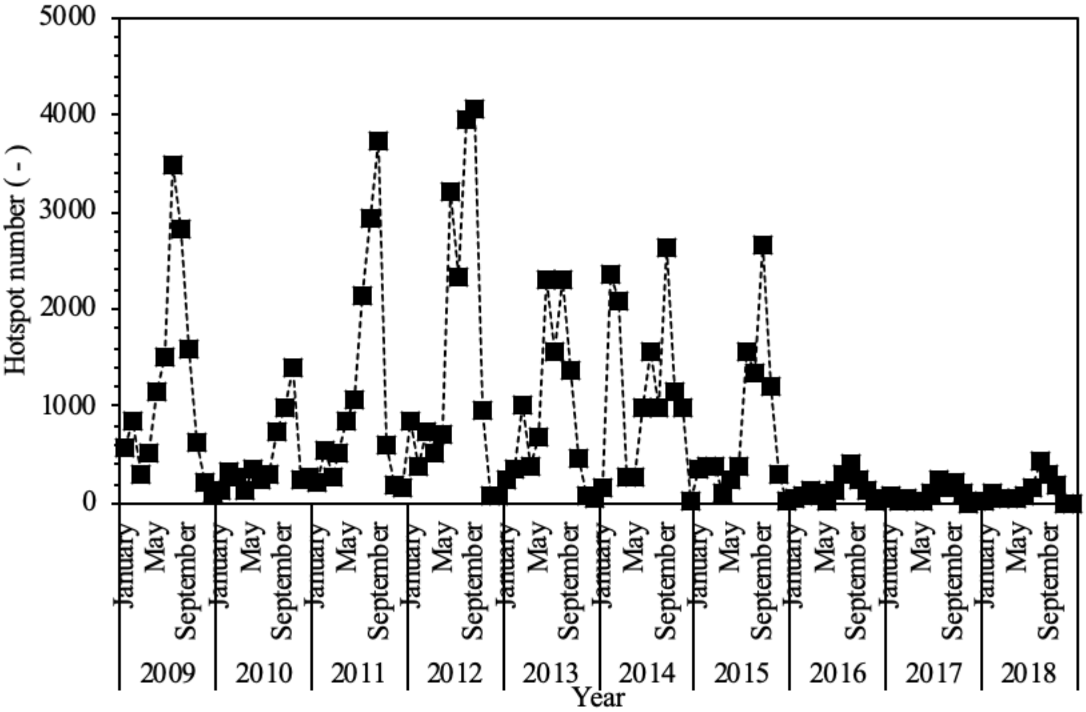


Figure 5.4. Numbers of yearly hotspots in Sumatra Island (2009-2018), Indonesia.

Sources: ASMC, 2019

5.3.2. Season and location influenced on PMs and carbonaceous fraction

In both seasons, the highest PMs levels were founded in Pekanbaru following by Jambi and Padang city, might be related to the increasing of pollutants level emitted from local sources. It can be seen from the **Figure 5.5 and Figure 5.6**, where in order, the size distribution and mass fraction of each size of particles were shown. Regardless the season, the distribution of each size of particles at the Jambi and Pekanbaru sites were similar, which the highest fraction was found at the size <1 μm, however, the PMs levels was different between each site. In Padang city, the peaked fraction was found around >1 μm suggested the coarser particles was dominated the size-fraction in this site which the PMs levels were significantly less than other two sites indicated, suggested these three sites were influenced the different types of local emission. It is confirmed by the one way non repeated ANNOVA test for all grouped of PMs (TSP, PM_{10}, $PM_{2.5}$, PM_1, and $PM_{0.1}$) that concluded the different of PMs level among three sites was significance ($p < 0.05$) in both seasons.

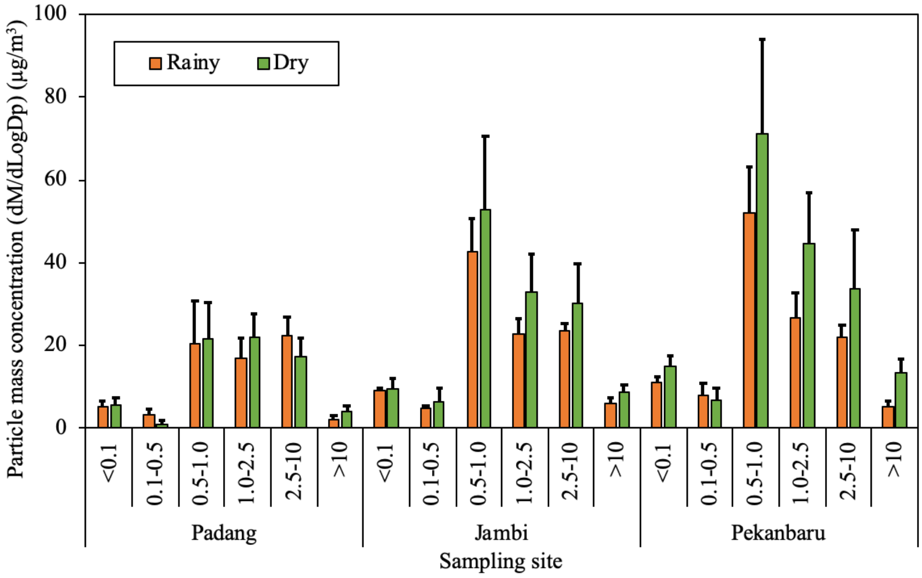


Figure 5.5. Particle size distribution observed at the study sites in Sumatra-Island

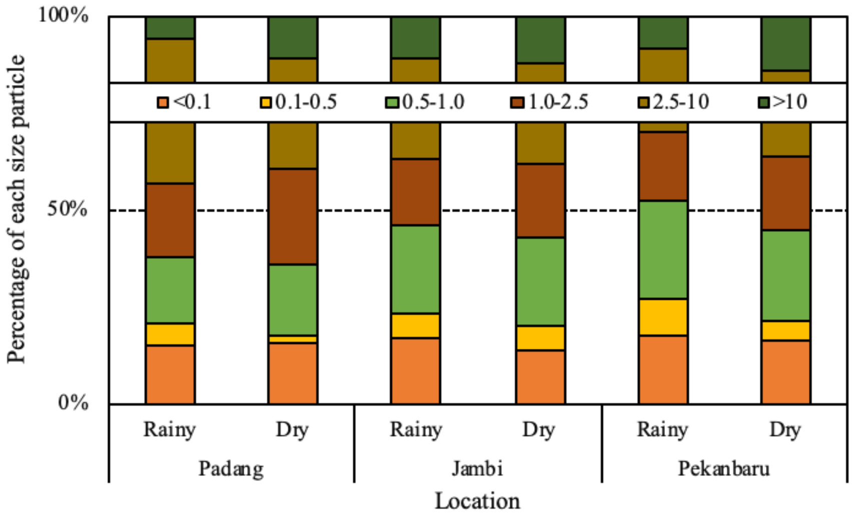


Figure 5.6. Size fraction of particles on a mass basis observed at study sites in Sumatra Island

Comparing the different of PMs level between rainy and dry season, In Jambi and Pekanbaru, the PMs levels were increasing from rainy to dry season, while in Padang city, almost no seasonal different between both seasons were found taking into account of each size distribution or PM level. It is confirmed by the independent sample t-test which p-value obtained was higher than >0.05 indicated the insignificant different between season as seen in the **Table 5.2.** In contrast, the p-value obtained in Jambi and Pekanbaru was lower than 0.05 that suggested the different of PMs level in both seasons were significance, unless the smaller particles or UFP and PM_1 at the Jambi site.

Table 5.2. Summary of the independent sample t-test comparing seasonal different between rainy and dry season in Sumatra Island, Indonesia

PMs	Padang	Jambi	Pekanbaru
$PM_{0.1}$	0.41	0.329	0.002
PM_1	0.37	0.101	0.036
$PM_{2.5}$	0.39	0.050	0.015
PM_{10}	0.34	0.042	0.016
TSP	0.49	0.030	0.005

One of the important factors affected the PMs level in both seasons is the meteorological conditions in each site. The backward air mass trajectory in both seasons also an important influenced to the PMs level as shown in **Figure 5.7.** that shown along with the distribution of hotspots in both seasons. **Figure 5.7**. are the hotspots and backward air mass trajectory in rainy season that is clearly seen, it was originated from the ocean regardless the locations. It is suggested that peatland fires influenced may be not an important issue, however, a less transboundary influence from the other countries in the northern parts of Sumatra island could not be ignored. Thus, the variation of chemical components in rainy season in each site should be influenced by the different of local emission sources. Regardless the season, backward air mass trajectory arrived at the Padang site were from the ocean, i.e., South China sea and Indian ocean, respectively for rainy and dry season. This is might be the reason of the lowest concentration compared to other sites and no different between both seasons **(Bousiotis et al., 2018)**. Besides, the precipitation is also one of the possible reasons since the different of the intensity of rainfall in both seasons was very small **(BMKG, 2015).**

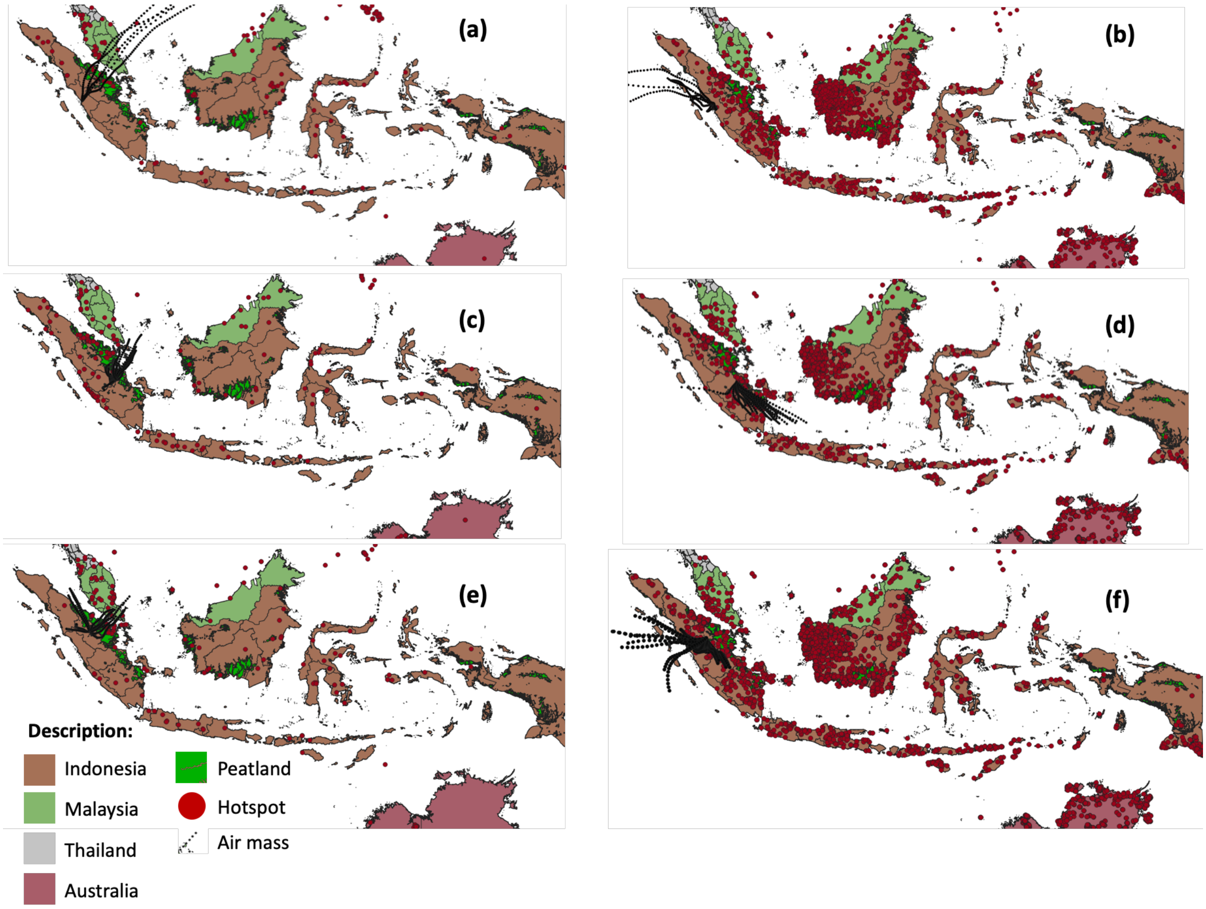


Figure 5.7. Seasonal air mass backward trajectory in Sumatra Island (a) Padang (rainy), (b) Padang (dry), (c) Jambi (rainy), (d) Jambi (dry), (e) Pekanbaru (rainy) and (f) Pekanbaru (dry)

As displayed in **Table 5.3 and Figure 5.8,** these data informed the effect of season and location to the characteristic of PMs related to its carbonaceous components. In Padang site, the OC/EC (8.19) was two times larger than in other sites during the rainy season (4.05 and 4.55 at Jambi and Pekanbaru sites, respectively). It could be related to the lower importance of traffic emission compared to other sites. At Jambi and Pekanbaru, the tendencies of carbonaceous components were comparable which the peak value of EC was found in $PM_{0.5-1}$. These values were much higher than Padang sites indicated in both sites were more affected by vehicles emissions. As reported by **Han et al., (2009),** the EC, particularly soot-EC generally associated to the diesel exhaust. The Environmental situation surrounded by Jambi and Pekanbaru sites might be similar with more influenced by the traffic at Pekanbaru site due to its location in the city central of Pekanbaru. It can be seen that the EC and soot-EC were consistently higher at Pekanbaru site compare to Jambi site. Both parameters were higher in the smaller particles or UFP and $PM_{0.5-1}$, and it was consistent regardless the season indicated the local emission taking into account traffic emission was stable throughout the year. The decline of soot-EC/TC in the dry season could be affected by the influenced of peatland fires emission in both sites especially in $PM_{0.5-1}$ which commonly sensitive to the biomass burning.

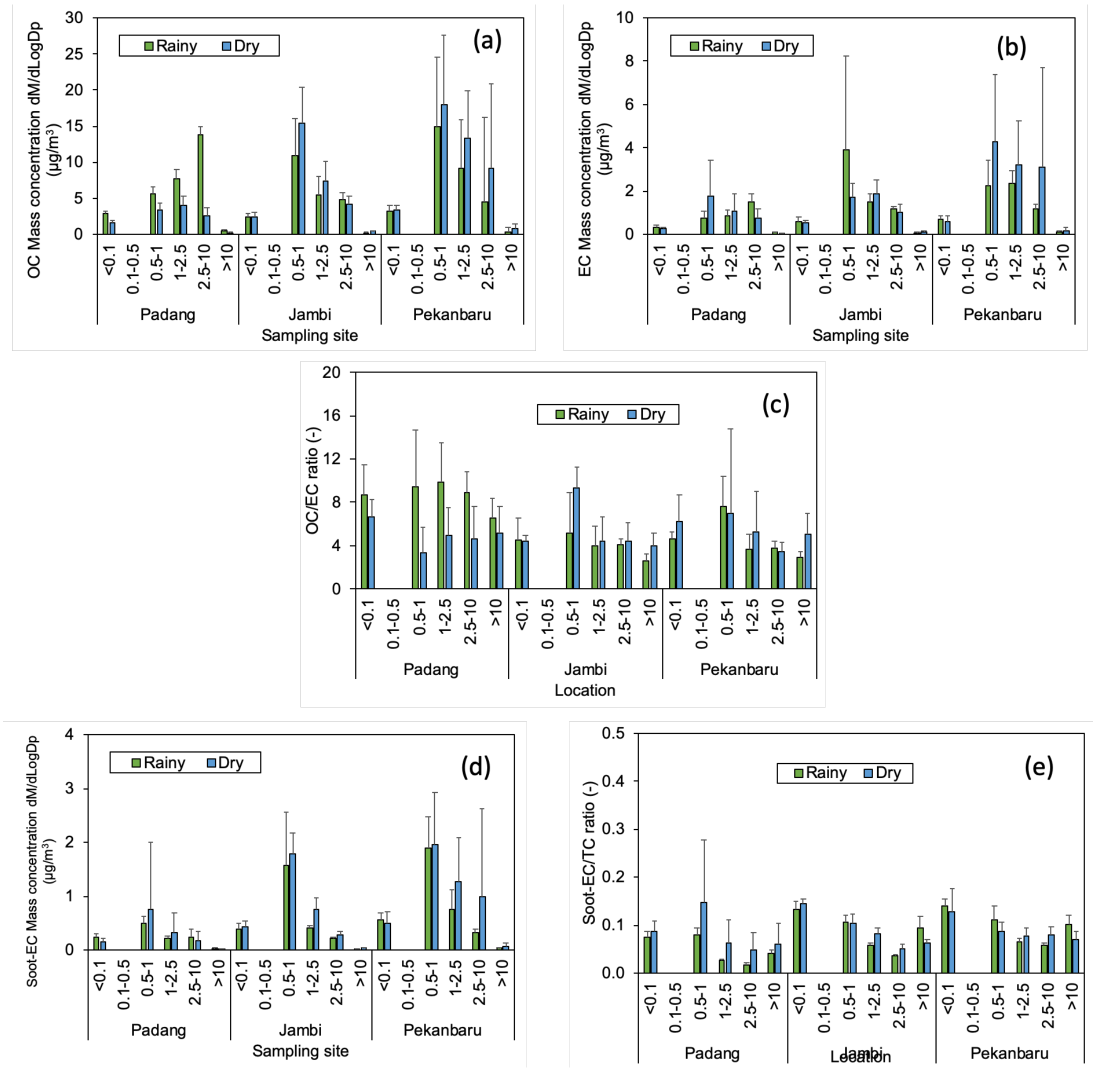


Figure 5.8. Carbonaceous component in three different cities in Sumatera Island (a) OC (b) EC (c) OC/EC (d) soot-EC (e) soot-EC/TC

Table 5.3. Seasonal average concentrations of carbonaceous components in Sumatra Island

Location	Season	Size (μm)	OC (μg/m^3)	EC (μg/m^3)	TC (μg/m^3)	Soot-EC (μg/m^3)	OC/EC (-)	Mass (μg/m^3)	TC/Mass (-)	Soot-EC/TC (-)
Padang	Rainy	<0.1	2.82	0.34	3.16	0.24	8.19	5.36	0.59	0.08
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	2.17	N/A	N/A
		0.5-1	1.70	0.22	1.92	0.15	7.68	6.15	0.31	0.08
		1-2.5	3.08	0.34	3.42	0.09	9.02	6.73	0.51	0.03
		2.5-10	8.34	0.91	9.25	0.14	9.13	13.44	0.69	0.02
		>10	0.53	0.08	0.62	0.02	6.42	2.13	0.29	0.04
	Dry	<0.1	1.57	0.25	1.82	0.16	6.34	5.57	0.33	0.09
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	0.77	N/A	N/A
		0.5-1	1.03	0.53	1.56	0.23	1.93	6.56	0.24	0.15
		1-2.5	1.58	0.43	2.01	0.12	3.69	8.69	0.23	0.06
		2.5-10	1.59	0.44	2.04	0.10	3.60	10.36	0.20	0.05
		>10	0.19	0.05	0.24	0.01	4.10	3.92	0.06	0.06
Jambi	Rainy	<0.1	2.40	0.59	3.00	0.40	4.05	9.20	0.33	0.13
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	3.47	N/A	N/A
		0.5-1	3.28	1.17	4.46	0.47	**2.81**	12.45	0.36	0.11
		1-2.5	2.15	0.59	2.74	0.16	**3.66**	9.09	0.30	0.06
		2.5-10	2.86	0.70	3.56	0.13	4.07	14.09	0.25	0.04
		>10	0.18	0.08	0.26	0.02	2.42	6.05	0.04	0.09
	Dry	<0.1	2.45	0.55	3.00	0.43	4.44	9.61	0.31	0.14
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	4.56	N/A	N/A
		0.5-1	4.62	0.51	5.13	0.54	**9.03**	15.94	0.32	0.10
		1-2.5	2.96	0.73	3.70	0.30	**4.03**	13.18	0.28	0.08
		2.5-10	2.55	0.63	3.17	0.16	4.07	18.28	0.17	0.05
		>10	0.42	0.11	0.53	0.03	3.82	8.77	0.06	0.06
Pekanbaru	Rainy	<0.1	3.22	0.71	3.93	0.55	4.55	10.92	0.36	0.14
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	5.64	N/A	N/A
		0.5-1	4.47	0.68	5.15	0.57	**6.55**	15.64	0.33	0.11
		1-2.5	3.64	0.93	4.57	0.30	**3.90**	10.61	0.43	0.06
		2.5-10	2.71	0.72	3.43	0.20	3.75	13.17	0.26	0.06
		>10	0.28	0.10	0.37	0.04	2.82	5.35	0.07	0.10
	Dry	<0.1	3.30	0.61	3.91	0.50	5.41	15.16	0.26	0.13
		0.1-0.5	N/A	N/A	N/A	N/A	N/A	4.70	N/A	N/A
		0.5-1	5.39	1.29	6.69	0.59	**4.17**	21.48	0.31	0.09
		1-2.5	5.27	1.27	6.54	0.51	**4.16**	17.79	0.37	0.08
		2.5-10	5.53	1.88	7.41	0.59	2.95	20.20	0.37	0.08
		>10	0.82	0.17	0.98	0.07	4.91	13.36	0.07	0.07

Description: N/A: not analyze

5.3.3. Biomass burning influenced during dry season

The air mass trajectory shown in **Figure 5.7.,** the air mass trajectory arrived at the sampling sites were passed through the peatland area in dry season, in where many of hotspots distributed, except in Padang city. The influence of biomass burning should affect to Jambi and a slightly influenced might be affected the Pekanbaru site due to some of the air mass were originated from ocean. In Jambi, during dry season, the air mass was originated from the southern parts or from South Sumatra and Lampung province in where many hotspots distributed in both provinces particularly in the peatland and agricultural area as seen from **Figure 5.9**. and **Figure 5.10. (Permadi and Kim Oanh., 2013),** while in Pekanbaru site, even several of the air mass arrived at the sampling sites was come from ocean, the others of air mass were moved through the hotspots area that indicated biomass burning influenced was also an important factor. Taking into account the carbonaceous components, the OC, EC, and TC components were increased particularly at particle sizes 0.5-1 and 1-2.5 μm in both sites. Especially in Jambi, in these particles size, the OC/EC ratio also increased. The trend of OC/EC ratio was comparable between these sites in dry season suggested that biomass burning events in this island was the main factors, which previously reported by **Fujii et al., (2015).** It is also comparable with the OC/EC ratio founded by **Hayasaka et al., (2014)** in the central Kalimantan (3.88-14.75) during dry season 2010-2012. While the present value was significantly lower than that value reported by **Fujii et al., (2015)** in the Riau province (36.4±9.08) due to the previous data was sampled in the peatland area where the fires took placed.

Other parameters to overview the discussion on carbonaceous components related to the biomass burning influenced, the correlation of OC/EC ratio versus EC for UFP and $PM_{0.5-1}$ was performed. These data were plotted in the **Figure 5.11**. To confirm it, the similar data sampled in the urban area of Asian countries were plotted at the same figures to specify whether the present study were closed to the "urban" or move to the "biomass burning" as reported by **Amin et al., (2021).** The data from Asian countries was called an urban correlation due to its characteristic sampling sites in where the traffic emission might be the dominant sources **(Kim et al., 2011a; 2011b; Thuy et al., 2018; Phairuang et al., 2019; Putri et al., 2021).** The selected particles or UFP and $PM_{0.5-1}$ were due to UFP commonly affected by fresh burning both from biomass and vehicle emission while $PM_{0.5-1}$ was very sensitive to the biomass burning as reported so far. Based on the Figure 5.11 (a). the UFP and $PM_{0.5-1}$ in Padang site in both seasons were located at the same correlation with other Asian countries, suggested a less influenced of biomass burning in this site, as discussed previously. In Jambi, the UFP was located at the urban correlation might be due to the dominant influenced of traffic emission. In contrast for the $PM_{0.5-1}$ at Jambi site and UFP and $PM_{0.5-1}$ at Pekanbaru site in both seasons, these data were move from the urban correlation to the biomass burning correlation in the upper-right side indicated the larger influenced of biomass burning. However, the influenced of peatland fires in Jambi site was larger than Pekanbaru site as seen from the air mass trajectory.

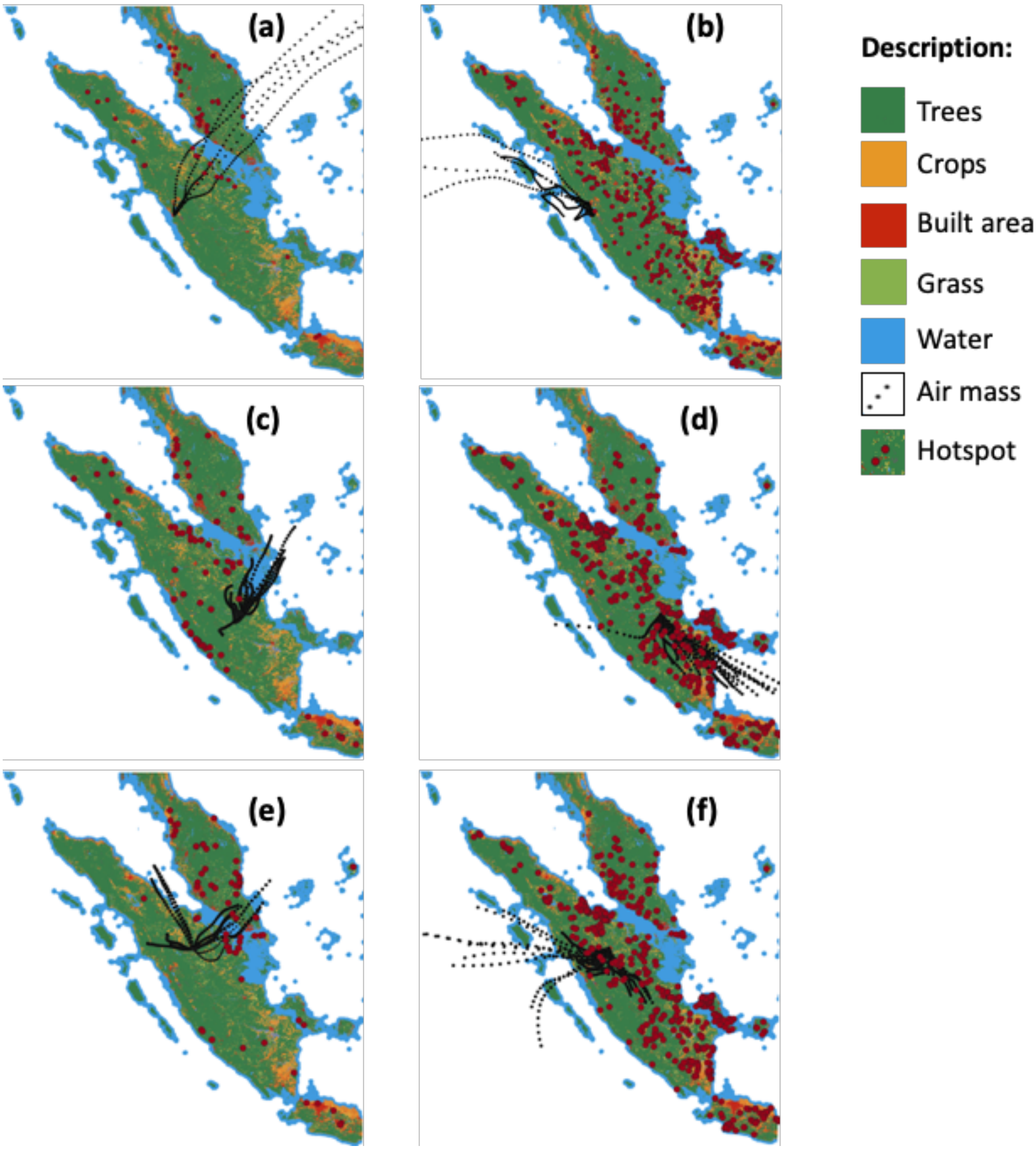


Figure 5.9. Overlap land cover of Sumatera Island and air mass trajectory during dry and rainy season in all sampling location (a) Padang (rainy), (b) Padang (dry), (c) Jambi (rainy), (d) Jambi (dry), (e) Pekanbaru (rainy) and (f) Pekanbaru (dry)

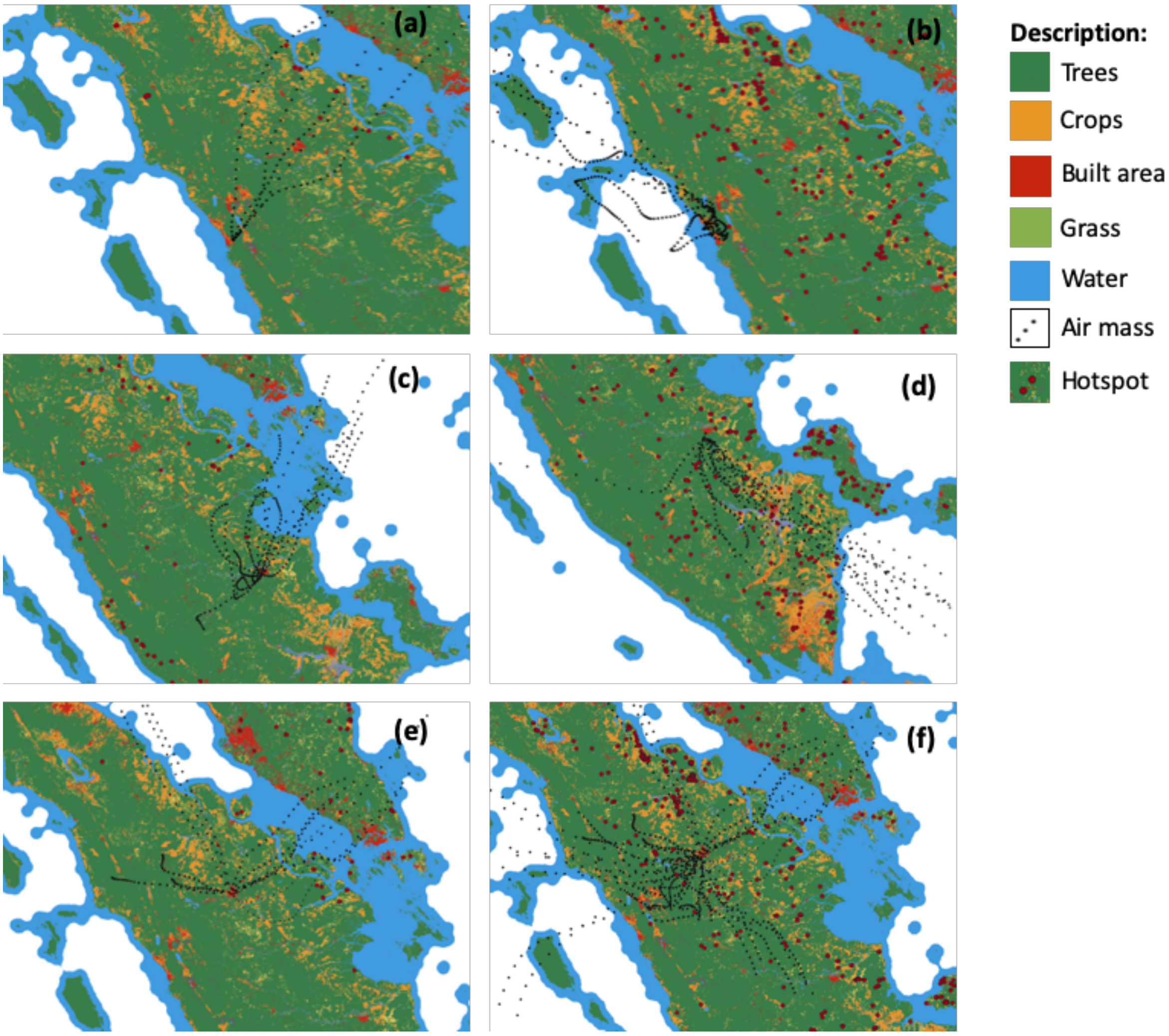
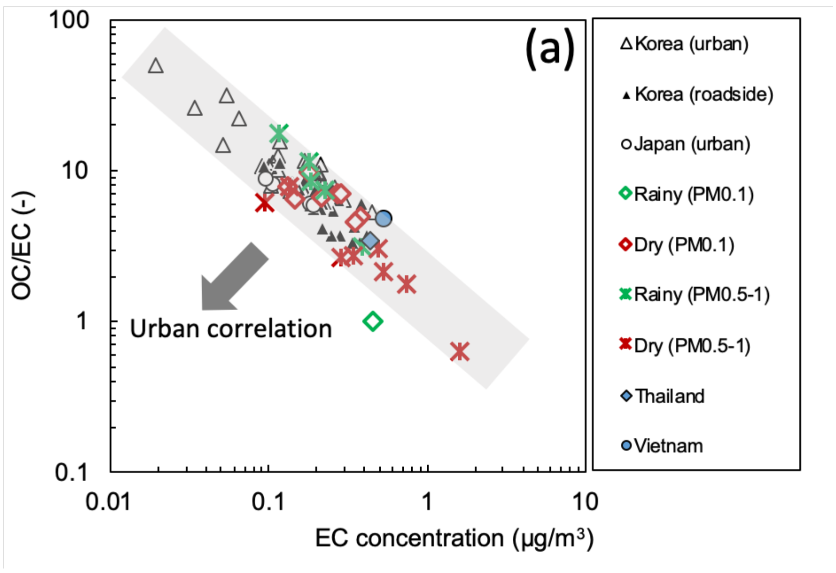


Figure 5.10. Detail overlap land cover of Sumatera Island and air mass trajectory during dry and rainy season in all sampling location (a) Padang (rainy), (b) Padang (dry), (c) Jambi (rainy), (d) Jambi (dry), (e) Pekanbaru (rainy) and (f) Pekanbaru (dry)



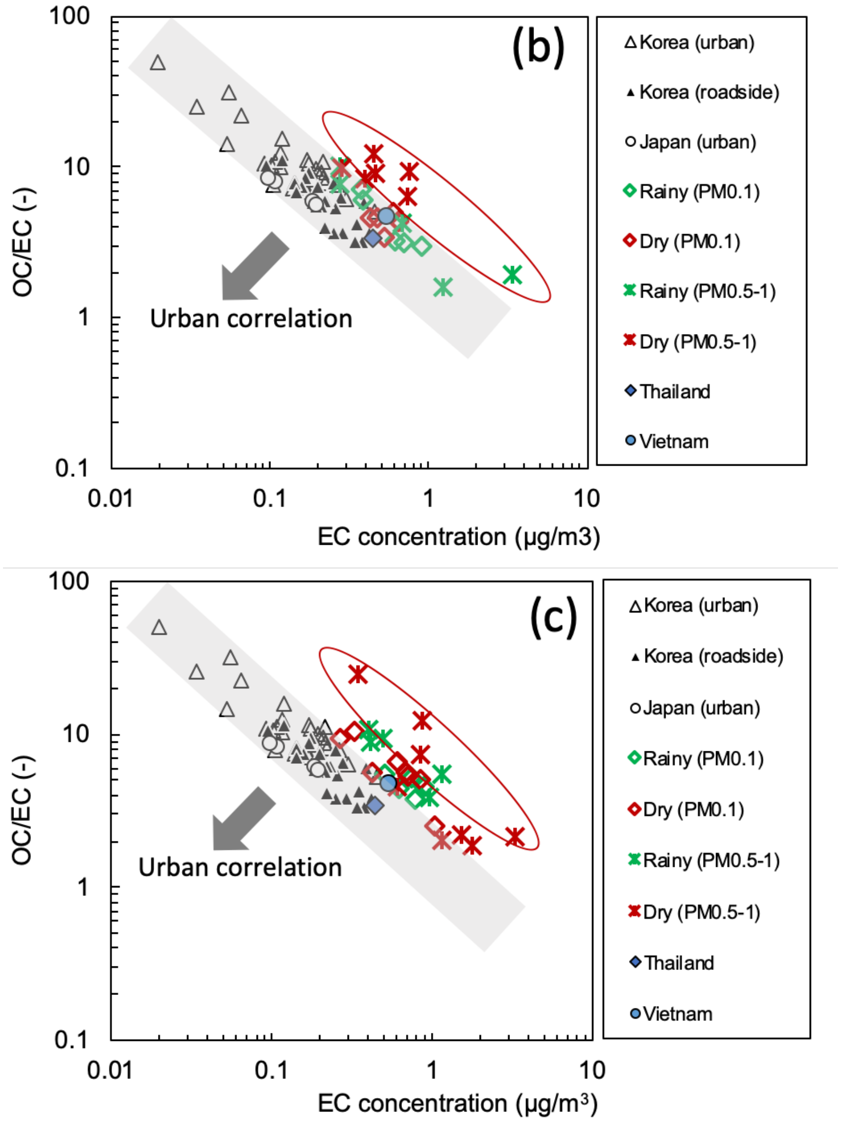


Figure 5.11. Comparison of OC/EC ratio to mass concentration of EC in the $PM_{0.1}$ and $PM_{0.5\text{-}1}$ in the East Asia (a) Padang (b) Jambi (c) Pekanbaru

5.4. Conclusion

The different of size-segregated particulate matters (PMs) in the rainy and dry season, in Sumatra Island, Indonesia were investigated in 2018. Regardless the season, the $PM_{2.5}$ and PM_{10} in Pekanbaru site exceeded the WHO guidelines. In Jambi sites, only PM_{10} in rainy season was lower than that standard in rainy season, while in Padang site, the $PM_{2.5}$ and PM_{10} in both seasons were still acceptable. The UFP in Jambi and Pekanbaru also comparable to the data observed in Asian countries. During dry season, A significant contribution of peatland fires was founded particularly in the east coast of Sumatra Island due to the large number of air mass trajectory surrounded both sites. In contrast, that factor was not important in Padang site since in both season the air mass originated from the ocean. The PMs level was highest in Pekanbaru following by Jambi and Padang site in both seasons. The correlation of OC/EC vs. EC for UFP was dominantly affected by vehicles emission regardless the season and location. It is confirmed by the highest fraction of soot-EC in UFP compare to other sizes. As to the transboundary effect, the particle sizes at 0.5-1 μm were more responsive for the biomass burning influenced as its correlation was move from the urban to the biomass burning side correlation. UFP in both Jambi and Pekanbaru, only slightly associated with the biomass burning. Based on soot-EC/TC ratio and confirmed by the OC/EC vs. EC correlation, Jambi and Pekanbaru cities were affected by the biomass burning particularly from peatland area during dry season. Other chemical associated with the indicator of typical emission sources should be conducted in the future study to provide more comprehensive understanding about the seasonal different of PMs including UFP during rainy and dry season.

5.5. Literature cited

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Chapter VI
UFPs in Indonesia during the pandemic COVID-19

6.1. Objectives of the study

In this study, the change of PMs concentration particularly UFPs and carbon component related was evaluated during the pandemic COVID-19 in Indonesia to understand comprehensively its effect to the air quality. Since the COVID-19 is a pandemic, every country in the world was tightly rules the human activities outdoor and indoor which is affected to the reduce the use of vehicles outside. However, the study related the change of human behavior during the pandemic affected to the air quality particularly UFPs status were did not cover yet. Hence, in this chapter, the study related above issue was performed to cover the gap. The carbonaceous component especially soot-EC that is related to vehicle emission was also evaluated.

6.2. Sampling location

To evaluate the effect of COVID-19 pandemic to the air quality especially related to UFPs in Indonesia, a sampling site located in Jambi city or in the east coast of Sumatra Island was chosen. During the dry season, this city is affected by the open biomass burning particularly from the peatland fires surrounded the city. The selected site was located in the roof top of the residential building (2nd floor). It is nearby one of the main streets in Jambi city which is one of the possible emission sources in this area and located nearby the city center. For the comparison, the data during the lockdown period was compared with the data during the normal season in 2018 and 2019. The data in 2018 was sampled in the Jambi University **(Amin et al., 2021)** in the Muaro Jambi regency surrounded by greenbelt trees in both rainy and dry season. The detailed of sampling sites was explained previously in the **section 4.2.** Then, the data in 2019 was recorded in the offices of Jambi governor **(Amin et al., 2021).** The detail of sampling site is explained in the **section 5.2** in the previous chapter. As same as the location during the lockdown period, the sampling site in 2019 during dry season was nearby street, however it was less busy due to it is located in the institutional area. Even the sampling sites was different, the comparison seem to be reasonable since the sites still located at the same city. The detail description of Jambi city was mentioned also in the **section 4.2** above such as meteorological condition. During the lockdown period, sampling was conducted from December 2020 until August 2021. Total 27 sets of samples were collected during the study period. The detail of both sampling sites and meteorological condition in both locations were shown in **Figure 6.1 and Table 6.1**, respectively.

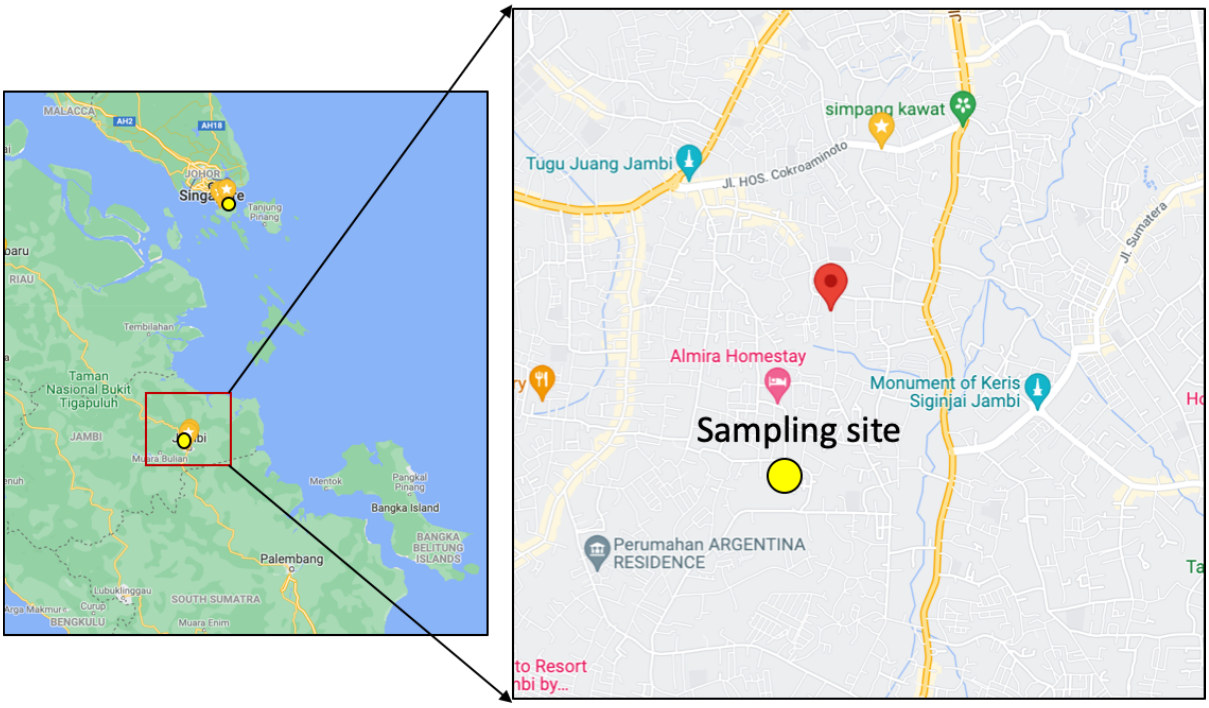

Figure 6.1. The sampling site during the pandemic COVID-19 in Jambi city, Sumatra Island, Indonesia

Table 6.1. Sampling period, duration and meteorological condition in Batam and Jambi cities

City	Period	Total (n)	Temp (°C)	Humidity (%)	Precipitation (mm)
Jambi	December 2020 – August 2021	27	27.2 ±0.8	80.5 ±3.8	2.7±4.0

6.3. Result and discussion

6.3.1. PMs concentration during COVID-19 outbreaks

The figures **6.2. (a) and 6(b)** shown the grouped PMs concentration and each particle size during the lockdown period, respectively. During the whole period of study, in both sites the UFPs concentration were more stable compare to other PMs might be related to the stable of emission sources of UFPs. The TSP in Jambi were ranged from 23.4 – 64.8 μg/m^3 while the UFPs level was ranged from 2.2 – 7.0 μg/m^3.

The air quality taking into account the PMs concentration during the COVID-19 pandemic were improved as seen from **Figure 6.3.** During the COVID-19 pandemic, around 90% of PM_{10}

was satisfied to the WHO guidelines (daily average = 50 μg/m^3) while for $PM_{2.5}$, only around 37% of the data exceeded the WHO guidelines which 63% of that value was below the WHO guidelines (daily average = 25 μg/m^3) **(WHO, 2006).** To the contrary, before the COVID-19, the all of the $PM_{2.5}$ and 62% of the PM_{10} data were exceeded that indicated the improvement of air quality in this city due to the limitation of human activities during the pandemic COVID-19 in Indonesia **(Resmi et al., 2020; Jephcote et al., 2021; Nigam et al., 2021).**

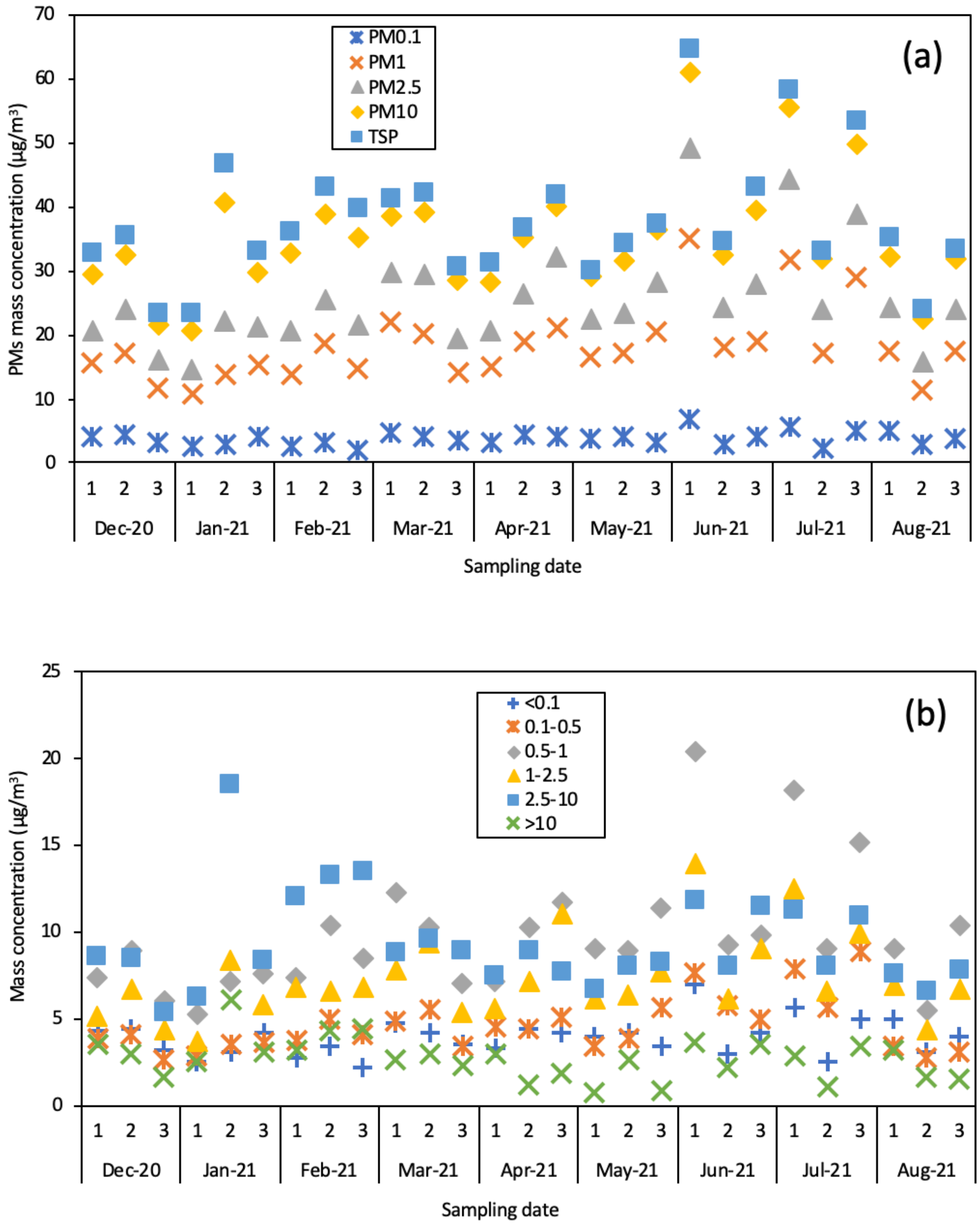

Figure 6.2. The grouped PMs (a) and each size of particles (b) concentration in Jambi city, Sumatra Island, Indonesia

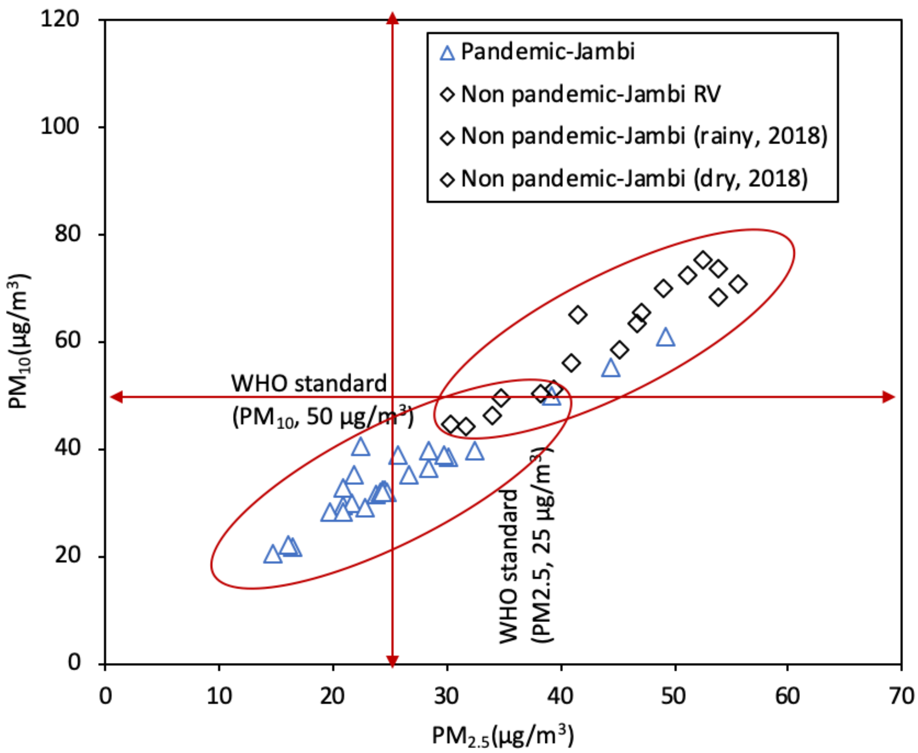

Figure 6.3. $PM_{2.5}$ and PM_{10} comparison with the WHO guidelines for 24-hours average

6.3.2. UFPs decreased during the pandemic COVID-19

To discuss the different between the PMs level before and during the pandemic COVID-19. UFPs level is one of the important factors since it was linked directly to the fresh emission of human activities **(Manigrasso et al., 2019).** In urban area, predominantly UFPs emitted from the vehicle emission, residential activities such as heating, cooking, etc. and industrial processes **(Soppa et al., 2019; Madureira et al., 2020).** However, vehicle emission is the most important factor taking into account in the urban site **(Slezakopa et al., 2014; Cavaleiro rufo et al., 2016).** Since during the study period, Indonesia is one of the most affected countries in SEA regarding the number of COVID-19 cases, the government of Indonesia, tightly ruled the citizens activities both indoor and outdoor. It can be said that the used of vehicles dramatically decreased during the pandemic COVID-19 periods.

As a result, the PMs level during the month of study period during the COVID-19 pandemic was totally decreased compared with that value before the pandemic both for each size of particles and grouped of PMs as displayed in **Figure 6.4 (a) and (b),** especially for the UFPs as shown in **Figure 6.5.** In Jambi city, during March 2021, the UFPs concentration decreased more than 50% while in August, the decreased was ranged from 58-68% compared to the value in August before Pandemic COVID-19 **(Donateo et al., 2021).** The highest decreasing was found in the UFPs and coarser particles might be due to the limitation of human activities outside. The value of UFPs during this period was comparable with the values recorded at the Kanazawa University (located at the hill, surrounded by green area) in Kanazawa city or a small city in Japan **(Hongtieab et al., 2020).** UFPs level was similar throughout the month indicated the common activities during the study period in this site.

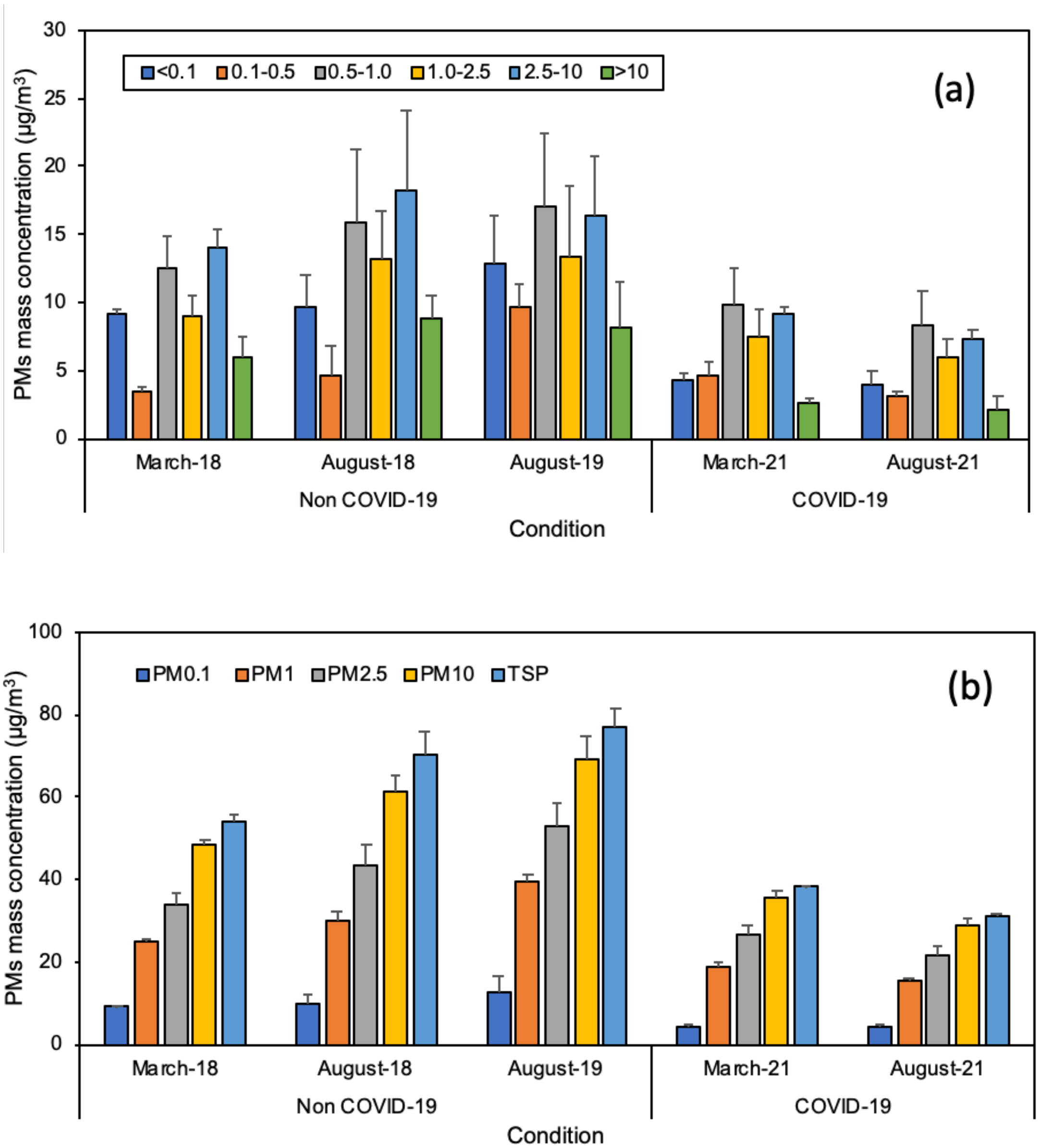

Figure 6.4. The comparison of PMs concentration before pandemic COVID-19 (normal condition) vs during the pandemic COVID-19 (a) each sizes of PMs (b) grouped of PMs

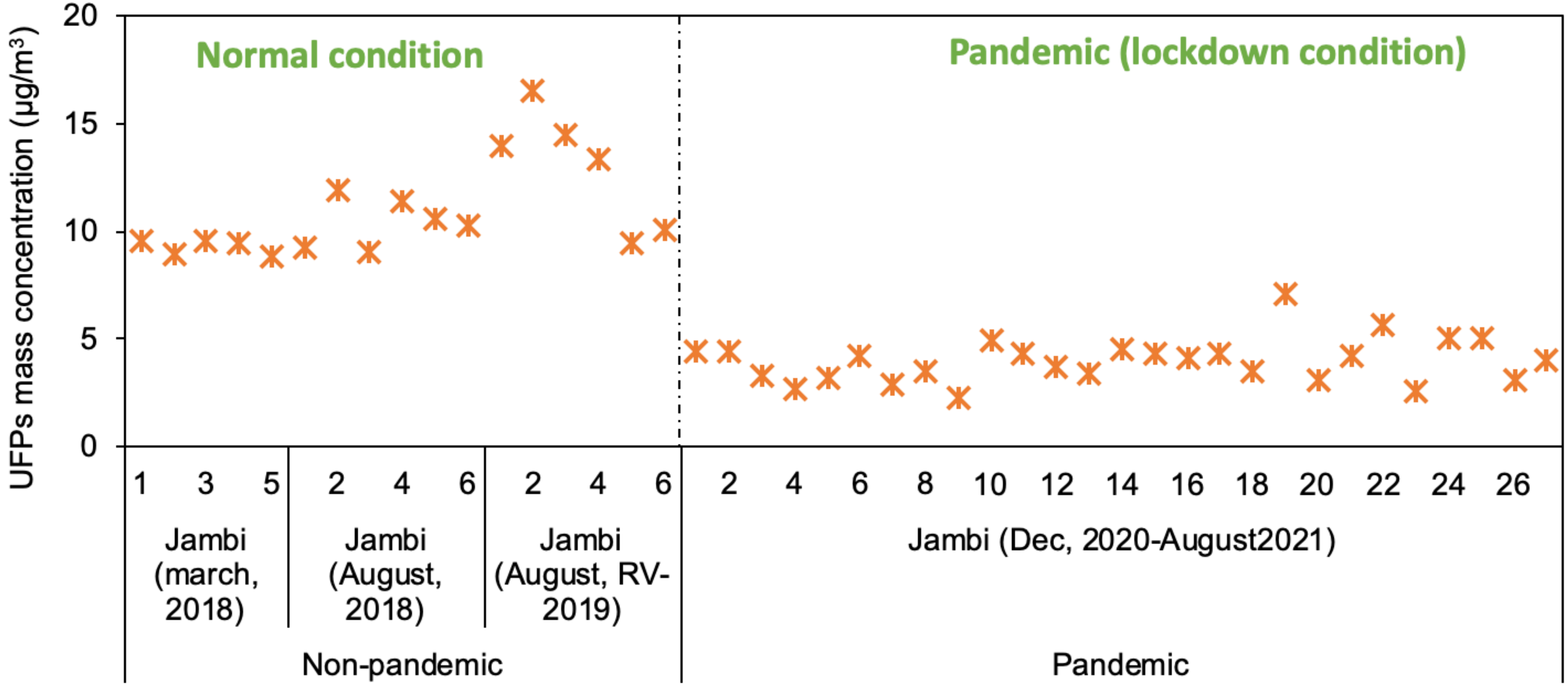

Figure 6.5. The comparison of UFPs concentration before pandemic COVID-19 (normal condition) vs during the lockdown during the pandemic COVID-19 in Sumatra Island, Indonesia

6.3.3. Carbonaceous component of UFP during the lockdown COVID-19 pandemic

To discuss the effect of COVID-19 pandemic to the improvement of air quality, another pollutant needed to discuss is carbonaceous component particularly, EC and soot-EC. Soot-EC is generally emitted from vehicle emission **(Demir et al., 2022). The Figures 6.6 (a-d)** shown the carbonaceous components or OC, EC, soot-EC, and OC/EC, respectively during the lockdown period in 2021 vs. the normal period in 2018 and 2019 during the rainy and dry season **(Amin et al., 2021).** It is clearly seen that the carbon component whether OC or EC was decreased during the lockdown periods. It is reasonable since the government of Indonesia and also the local government of Jambi city and Jambi province was asking the citizens to work and studied from home. During this period, the sources of pollutant should be decreased dramatically not only from the transportation sector but also from the biomass burning as the local restaurant or street vendors.

As the typical cities in Indonesia, in Jambi also has a lot of street vendors that used the biomass as the energy sources for cooking. Since the pandemic covid-19 outbreaks, the street vendors activities in some periods was prohibited by the government. The OC concentration during the lockdown periods was less than the data in 2018 in both rainy and dry season recorded in the country side of Jambi province in where far away from the emission sources and surrounded by the green-belt trees. It was decreased more than 50% compared with the data in 2018 located in the suburban site. Compared to the data in 2019 recorded in the Jambi city, nearby Batanghari river, the current data or during the lockdown periods was totally decreased around 75%. **Figures 6.6 (b),** shown the decreasing of EC during the lockdown periods which accounted around 66% compared with the data in the riverside. Not only OC and EC, the soot-EC as shown in **Figures 6.6.(c) and 6.7.** that is particularly emitted from the vehicle emission was significantly decreased compared with the data in 2018 and 2019. It was decreased for 12 ~ 14% from the data in the suburban of Jambi province and almost decreased around 60% from the data in 2019 recorded in the riverside of Jambi city. Since the OC vs. EC, EC vs. char-EC and EC vs. soot-EC have a good correlation as since in the **Figure 6.8,** the decreasing carbonaceous component not only correlated with the decreasing of transportation **(Anil and Alagha, 2020; Goel et al., 2021)** users but also the activities used biomass. This finding indicated the important of motor vehicles limitation to the improvement of air quality taking into account soot-EC in Sumatra Island, Indonesia.

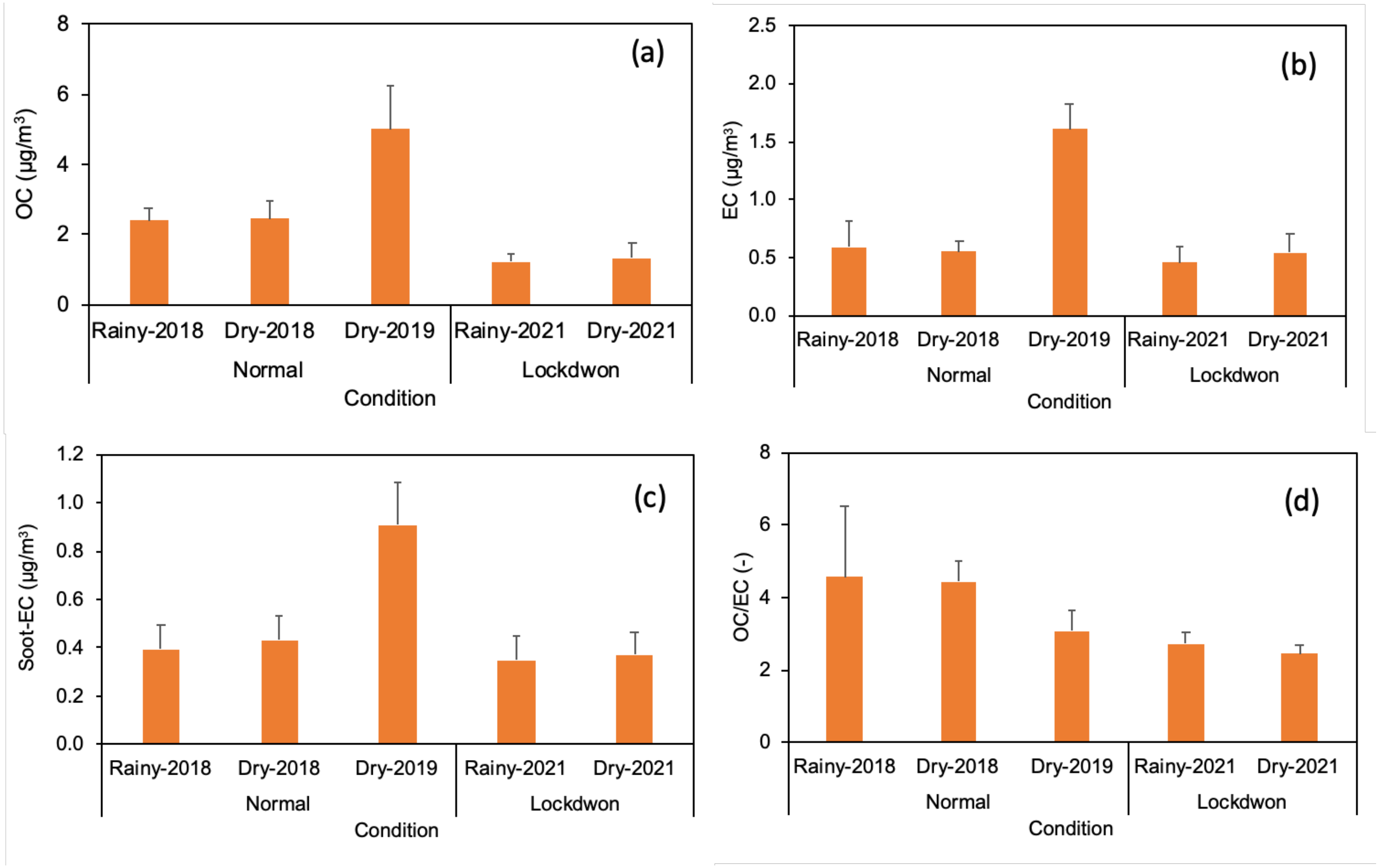

Figure 6.6. The comparison of soot-EC concentration before pandemic COVID-19 vs during the pandemic COVID-19 in Sumatra Island, Indonesia (a) daily (b) average concentration

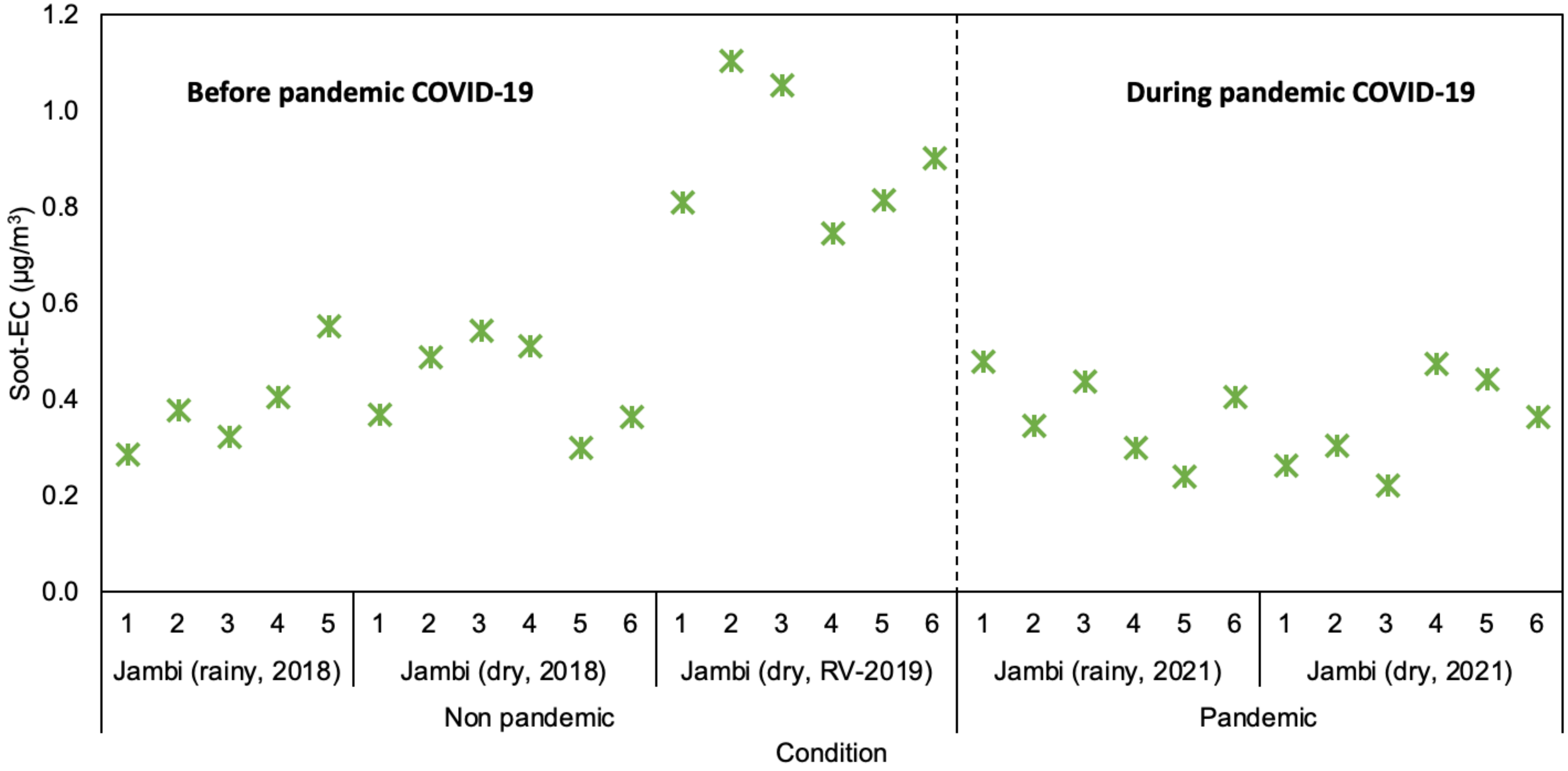

Figure 6.7. The comparison of soot-EC concentration before pandemic COVID-19 vs during the pandemic COVID-19 in Sumatra Island, Indonesia (a) daily (b) average concentration.

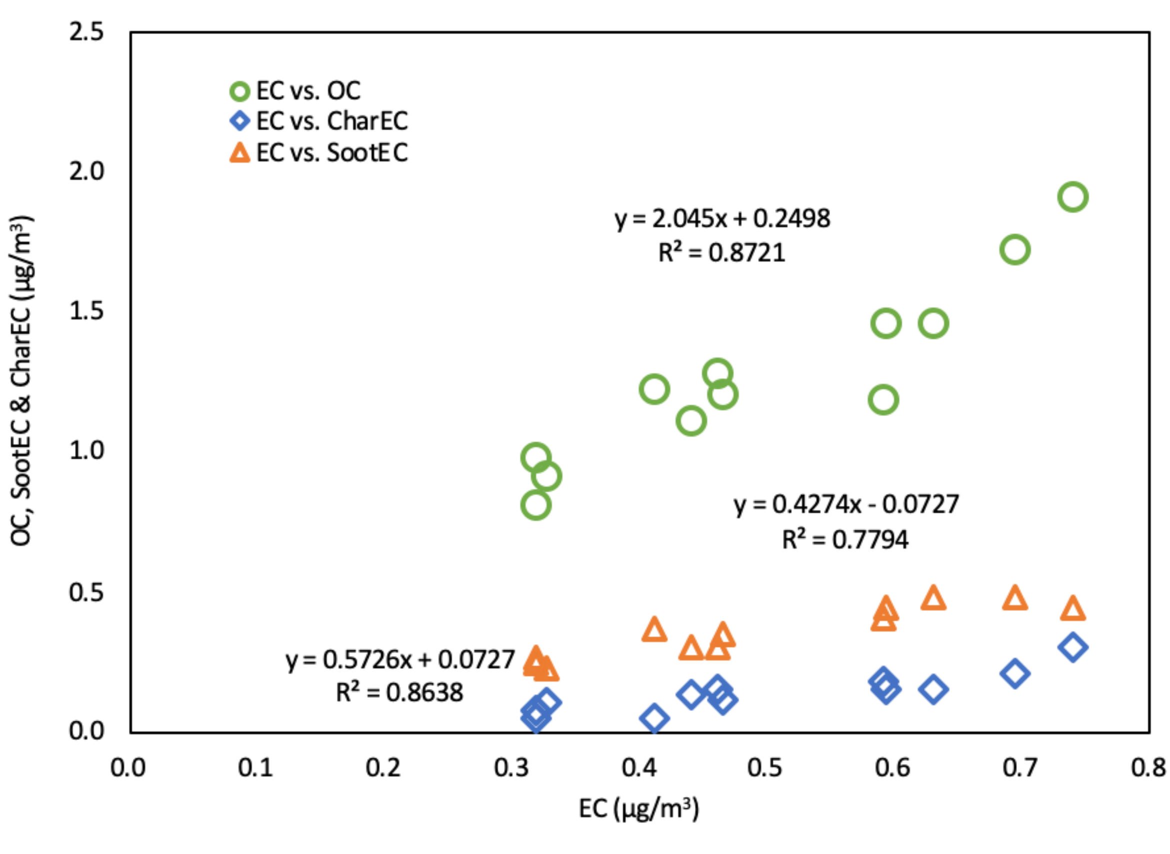

Figure 6.8. The correlation of carbonaceous component during the lockdown periods in 2021 (a) EC vs. OC (b) EC vs Char-EC (c) EC vs Soot-EC

6.4. Conclusion

The effect of COVID-19 outbreaks to the level of PMs particularly UFPs in Sumatra Island were investigated in Jambi city and compared with the data during the normal condition in 2018 and 2019 in both rainy and dry seasons. The PM_{10} in Jambi during the pandemic just around 10% of the data exceeded the WHO guidelines, while for $PM_{2.5}$, around 63% of the data meet the WHO standards. Before the pandemic, around 62% of PM_{10} and 100% of $PM_{2.5}$ were exceeded the WHO guidelines. Hence, the PMs level was totally decreased compared with the data before pandemic especially for UFPs. The TSP was ranged from 23.40 to 64.80 µg/m^3 with was totally lower than before the pandemic (up to 179 µg/m^3). Not only soot-EC that is related to vehicles emission but also other carbon components as OC and EC were decreased during the lockdown period indicated the improvement of air quality in Jambi city taking into account the UFPs level not only due to the decreasing number of vehicles user but also the used of biomass for the cooking in the residential area or street vendors or local restaurant.

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Chapter VII
Conclusion

7.1. Conclusion

The evaluated the status, characteristic, and sources of UFPs in Indonesia, the different between diurnal and nocturnal, dry and rainy season, before and after COVID-19, were evaluated in Indonesia. The diurnal and nocturnal of PMs was correlated with the number of vehicles especially related to the soot-EC concentration. The diurnal and nocturnal PMs concentration not only affected by the number of vehicles but also the meteorological condition as PBL. The seasonal effect to the PMs and its carbonaceous components were significant in Sumatra Island especially in east coast sites. The pandemic was caused the lower of PMs and its carbon components particularly to the indicator of vehicles emission as soot-EC.

7.2. Policy suggestion

7.3. Limitation of the study

This section explains some limitations of the study related to the data. Firstly, related to the number of samples collected which was still need more to discuss more comprehensively related to the diurnal and nocturnal, seasonal different, and also the effect of COVID-19 pandemics. Since the title was related to the Indonesia country, however, this study just focusses on Sumatra Island, yet, Indonesia has five major Island which have different characteristic taking into account the meteorological condition and local emission. The second issues are related to the chemical components analyzed in this study which just focused only about carbonaceous components. Even carbon component is the major component in the PMs, however, other chemicals such as ions, PAHs, trace metal are needed to discuss more comprehensively about the UFPs particularly taking into account its sources.

7.4. Future direction

There are two main points of the future directions based on the limitations above. Firstly, regarding the limitation of UFPs data, the monitoring sites in Indonesia should be added by working together with the Indonesian researchers in the different Island, so then, the UFPs status in each region of Indonesia will be available for the discussion related to the different characteristic of city. The second future direction is to add more chemical components related to UFPs especially related to the vehicle’s emission or fresh burning. It will give more understanding how each source, contributed to the status of UFPs in the atmosphere.