UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF SPATIO-TEMPORAL OF BLACK CARBON AEROSOLS IN URBAN AND SUBURBAN KLANG VALLEY, MALAYSIA

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ASSESSMENT OF SPATIO-TEMPORAL OF BLACK CARBON AEROSOLS IN URBAN AND SUBURBAN KLANG VALLEY, MALAYSIA

BY

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Thesis submitted in fulfilment of the requirement for the degree of Bachelor Science (Environmental and Occupational Health) from the Faculty of Medicine and Health Sciences, University Putra Malaysia

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ABSTRACT

ASSESSMENT OF SPATIO-TEMPORAL OF BLACK CARBON AEROSOLS IN URBAN AND SUBURBAN KLANG VALLEY, MALAYSIA

MUNIRAH BINTI YAMAN

Introduction: Black carbon (BC) is a global environmental problem for air pollution as it gives negative consequences to human health and climate. Vehicle and biomass emission are the main sources that contribute to the BC emission. Investigating the concentrations of BC is crucial as the concentration varied in time and space. **Objective:** This study aims to determine the real-time Spatio-temporal of black carbon aerosol concentration in urban and suburban Klang Valley. **Methodology:** The BC particle was measured using Aethalometer AE33 (Magee Scientific, USA) which was deployed at the rooftop of two campus faculty from July 2019 until October 2019 in Kuala Lumpur (urban) and Serdang (suburban) from December 2019 until February 2020. The AE33 is set for 1-min temporal resolution. **Results and Discussion:** Our study found that the average concentration of BC was higher in the urban site (Kuala Lumpur) compared to the suburban site (Serdang) with an average value of 4.5 µg/m^3 (2.3-3.5 µg/m^3) and 2.5 µg/m^3 (1.2-1.7 µg/m^3) respectively. Temporal variation was divide into several variations; First, monthly variation data showed that the value of BC concentration from July until October 2019 for Kuala Lumpur was higher compared to Serdang month of assessment (December 2019 - February 2020). Then hourly variation was observed for Kuala Lumpur and Serdang site showed similar peaks were at around 8-9 a.m. in the range of 6.7-7.3 µg/m^3 and 3.4-4.3 µg/m^3 respectively. Concentration of BC was found higher in the weekdays compared to weekends due to working hour patterns for both of the sites. The diurnal variation that been observed from continuous measurements of AE33 was separated into day (from 12 am until 11 am) and night (from 12 pm until 11 pm). Day time showed 43% and 50% higher BC concentration for urban and suburban. **Conclusion:** This study presented the spatio-temporal variation of black carbon concentrations in the urban and suburban of Klang Valley. Traffic emissions are suggested to influence the BC concentrations and become the dominant source for Kuala Lumpur (urban) due to its location. This study provides the baseline BC real-time data and deserved further investigation.

Keywords: Black carbon, Air pollution, Aethalometer AE33, Traffic, Urban and suburban

ABSTRAK

PENILAIAN SPATIO-TEMPORAL AEROSOL 'BLACK CARBON' DI BANDAR DAN PINGGIR BANDAR LEMBAH KLANG, MALAYSIA

MUNIRAH BINTI YAMAN

Pengenalan: **'**Black carbon' (BC) adalah masalah persekitaran global untuk pencemaran udara kerana ia memberi kesan negatif kepada kesihatan manusia dan iklim. Pelepasan kenderaan dan biomas adalah sumber utama yang menyumbang kepada pelepasan BC. Mengkaji kepekatan BC adalah penting kerana kepekatannya mempunyai variasi masa dan tempat. **Objektif**: Kajian ini bertujuan untuk menentukan masa nyata spatio-temporal bagi kepekatan aerosol 'black carbon' di bandar dan pinggir bandar dalam Lembah Klang. **Metodologi**: Partikel BC diukur menggunakan Aethalometer AE33 (Magee saintifik, Amerika Syarikat) yang ditempatkan di bumbung fakulti kampus dari Julai 2019 hingga Oktober 2019 di Kuala Lumpur (bandar) dan Serdang (pinggir bandar) dari Disember 2019 hingga Februari 2020. AE33 ditetapkan untuk 1 minit resolusi temporal. **Keputusan dan Perbincangan**: Kajian kami mendapati bahawa purata kepekatan BC menunjukkan lebih tinggi di kawasan urban (Kuala Lumpur) berbanding dengan kawasan pinggir bandar (Serdang) dengan nilai purata masing-masing 4.5 $\mu g/m^3$ (2.3-3.5 $\mu g/m^3$) dan 2.5 $\mu g/m^3$ (1.2-1.7 $\mu g/m^3$). Variasi masa dibahagikan kepada beberapa variasi; pertama, variasi bulanan menunjukkan bahawa nilai kepekatan BC dari Julai hingga Oktober 2019 untuk Kuala Lumpur lebih tinggi berbanding bulan penilaian Serdang (Disember 2019 - Februari 2020). Kemudian variasi setiap jam diperhatikan untuk lokasi Kuala Lumpur dan Serdang menunjukkan kedua-dua kawasan mempunyai puncak yang serupa pada sekitar jam 8 hingga 9 pagi masing-masing dalam lingkungan 6.7-7.3 $\mu g/m^3$ dan 3.4-4.3 $\mu g/m^3$. Kepekatan BC juga didapati lebih tinggi pada hari bekerja berbanding dengan hujung minggu kerana corak jam kerja untuk kedua-dua kawasan ini. Waktu siang menunjukkan kepekatan BC 43% dan 50% lebih banyak untuk bandar dan pinggir bandar. **Kesimpulan**: Kajian ini menunjukkan variasi spatio-temporal kepekatan 'black carbon' di bandar dan pinggir bandar Lembah Klang. Pelepasan aliran lalu lintas dianggapkan mempengaruhi kepekatan BC dan menjadi sumber dominan Kuala Lumpur (urban) disebabkan lokasi tempatnya. Kajian ini memberikan data asas masa nyata BC dan layak untuk penyelidikan lebih lanjut.

Kata kunci: **'**Black Carbon', Pencemaran udara, Aethelometer AE33, Aliran lalu lintas, Bandar dan pinggir bandar

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LIST OF ABBREVIATIONS

BC	Black carbon
AE33	Aethalometer model AE33
USA	United State of America
COPD	Chronic Obstructive Pulmonary Disease
US EPA	United State Environmental Protection Agency
PM	Particulate matter
OC	Organic carbon
WHO	World Health Organization
BB	Biomass burning
$PM_{2.5}$	Particulate matter with an aerodynamic diameter smaller than 2.5μm
PM_{10}	Particulate matter with an aerodynamic diameter smaller than 10μm
PAH	Polycyclic aromatic hydrocarbons
EC	Elemental carbon
WSOC	Water-soluble organic carbon
PB	Lead
Ce	Cerium
Sb	Antimony
Cd	Cadmium
As	Arsenic
Zn	Zinc
Ni	Nickel
Co	Cobalt
Mn	Manganese
Mg	Magnesium

Al	Aluminium
P	Phosphorus
K	Potassium
V	Vanadium
Cr	Chromium
ATN	Attenuation
GBD	Global Burden of Disease
GAINS	Greenhouse gas - Air Pollution Interaction System
PMF	Positive Matrix Factorization
ME-2	Multilinear Engine
SKVE	South Klang Valley Expressway
MAEPS	Malaysia Agro Exposition Park Serdang
USB	Universal serial bus
HDDV	Heavy-Duty Diesel Vehicle

CHAPTER 1

INTRODUCTION

1.1 Background

Air pollution is a global environmental health problem (WHO, 2018). Many health consequences can be induced by air pollution towards humans (Sissons, 2020). Short-term ingestion of air pollution is clearly linked with COPD (Chronic Obstructive Pulmonary Disease), cough, shortness of breath, wheezing, asthma, respiratory illness, and increase the length of hospital stay where even on days of low air pollution, the health of vulnerable and delicate people can be affected (Manisalidis et al., 2020). According to Manisalidis et al. (2020), long term effects of air pollution are chronic asthma, pulmonary insufficiency, cardiovascular disease, and cardiovascular mortality. It is also known that in 2012, from inhalation of contaminated air about 7.0 million people worldwide died (WHO, 2014).

There is six major components of air pollutants stated by USEPA (2018), which are ozone, particulate matter (PM), carbon monoxide, nitrogen oxide, sulfur dioxide, and lead. Explicitly particulate matter (PM) contamination signifies danger to both nature and human health (Rai, 2016), as PM brought into the air by natural and human activities in which it can be stay over a long time and travel over long distances in the atmosphere and provide a lot of diseases that lead to a potential decrease of human lifespan (Kim, Kabir & Kabir et al., 2015). Global anthropogenic particulate matter (PM) discharges including constant and coordinated figuring of mass-based size appropriation (PM_1, $PM_{2.5}$, PM_{10}) just as essential carbonaceous aerosols including black carbon (BC) and organic carbon (OC) (Klimont et. al, 2017). Black carbon was stated more robust than those PM it is a decision that they will fill as a better marker of unsafe particulate substances from major traffic-related ignition particles contrasted to undifferentiated PM mass (WHO, 2012).

Furthermore, black carbon is viewed as the main light absorber and is radiated into the ambient air and correlates with soot by incomplete anthropogenic ignition and biomass combustion (Koike et al., 2014; Laskin et al., 2015). Sattar et al., 2014 stated that automobile emissions from transportation are the main source of black carbon in the cities area. Black carbon exhibits a lot more within city inclination compared to rural, particularly in territories with high volumes of on-street sources (Luben et al., 2017).

In Malaysia, there is traffic-related air pollution and haze problem. In the Klang region there is an increase number of private traveler vehicle that has not just brought traffic congestion during peak hours but also resulted in vehicular emissions causing both environmental and human wellbeing danger (Bazrbachi et al., 2017). Heavy traffic can make substantial contributions for black carbon compared to particulate mass concentrations (Luben et al., 2017). Previous study mentioned that haze is related to an elevated level of air contaminations; it decreases visibility and influences human wellbeing in the influenced countries like Malaysia (Latif et al., 2018). Haze conditions have been connected with industrial exercises, traffic emanations and biomass burning (BB) (Liu et al., 2016). During severe haze events in China, high BC concentration was spotted (Andersson et al., 2015).

1.2 Problem Statement

Particulate mass (PM) concentration is one of the most challenging problems both for air quality and climate change policies (Fuzzi et al., 2015). One cluster of PM recognized, $PM_{2.5}$, have a small width, however, have large surface capacities and may consequently be fit for conveying different poisonous kinds of stuff, going through the filtration of nose hair, arriving at the end of the respiratory tract with airflow and aggregate thereby dispersion, harming different pieces of the body through air trade in the lungs (Xing et al., 2016). Other than that, because of their little width, particles in the $PM_{2.5}$ territory can harm airway cells, setting off a provocative reaction that reduces pneumonic insusceptibility and encourages irresistible microbe assaults (Jan et al., 2017). Due to deeper infiltration of $PM_{2.5}$, it enters the circulation system, prompting hypertension and harming veins. Once in the circulatory system, $PM_{2.5}$ can spread to different organs, for example, the heart, harming its cell structure and capacity (Feng et al., 2016). The impacts of human exposure to $PM_{2.5}$ are particularly critical in urban conditions, where the higher population density prompts higher poison generation and higher human exposure (Baklanov et al., 2016).

Black carbon is an important component of fine particulate matter ($PM_{2.5}$) that contributes to air pollution, which has been declared to be the biggest environmental risk to human health globally (WHO, 2016). Black carbon (BC) emissions being the strongest cause of climate change remains one of the biggest threats to life on earth after carbon dioxide (CO_2) (Raila and Anderson, 2016). In addition to direct climate impacts, black carbon also reduces the albedo effect of the surface (its ability to reflect sunlight), thereby further contributing to global warming (Yamineva and Liu, 2019). Other than that, a study found that dense city centers have a containment effect on black carbon emissions from fossil fuel-powered transportation, domestic stoves and space heating (Farrell et al., 2015). Black carbon (BC) is also stated to be one of the important aerosol component combustion-derived from haze (Liang et al., 2017).

Since BC efficiently enters human lung tissue, it causes serious health effects, such as oxidative injury, and increases pulmonary discomfort symptoms (Lin et al., 2015). Other than that, long-term exposure to BC can increase the risk of mortality related to cardiovascular diseases (Baumgartner et al., 2014). Some of the studies found that BC is associated with Type 2 diabetes (Sun et al. 2015), chronic obstructive pulmonary disease (Suh et al. 2011), and coronary arteries disease (Zanobetti et al. 2010).

This shows if we do not monitor into specific $PM_{2.5}$ component like black carbon aerosol emission we might not be able to reduce the increase of health effects due to an increase in black carbon trend. There are studies of black carbon in other studies, but limited studies were found in Malaysia. Over the past decades, urbanization in Klang Valley, Peninsular Malaysia has resulted in the threat of air emissions having negative environmental impacts (Jamalani et al., 2016). However, fast urbanization has also brought dramatic environmental problems. Malaysia experiences haze and traffic related air pollution which is the potential source of black carbon.

Therefore, in this study, we aim to assess the spatio-temporal of black carbon aerosol in urban and suburban Klang Valley. We plan to determine the black carbon aerosol concentration between urban (Kuala Lumpur) and suburban (Serdang). Other than that, we want to determine the temporal factor of black carbon aerosol in urban and suburban. We will also consider comparing black carbon aerosol concentration weekdays and weekends in urban and suburban and to determine between day against night of spatio-temporal of black carbon in urban and suburban.

1.3 Study Justification

Air Pollution in Malaysia varied temporally and spatially due to seasonal variation (Kanniah et al., 2016). Air pollution is a major environmental issue in Malaysia, highlighted only during haze but in normal days also very important to look at exposure to the population (Aghamohammadi and Isahak, 2018). Malaysia has problems with $PM_{2.5}$ (How and Ling, 2016), so as BC is part of $PM_{2.5}$ it is also affected (WHO, 2016). Black carbon is a climate change agent (Ji et al., 2015), study this pollutant is crucial.

According to Bazrbachi et al. (2017), they stated that Klang Valley is the fastest-growing region and developed urban areas in Malaysia as it is the economic nerve-center of Malaysia which contribute to the transportation pollution. According to the Malaysian Institute of Road Safety Research (MIROS), the registration of vehicles in Malaysia is significantly growing every year, as of 2016, over 27 million vehicles have been registered. Heavy traffic can make substantial contributions of black carbon compared to particulate mass concentrations (Luben et al., 2017). Klang Valley is a large area in Malaysia comprising Kuala Lumpur and its suburbs, adjoining cities and towns in the state of Selangor (Halim et al.,2017), so pollutants varied spatially. Diurnal factors, peak hour rush hours, day, and night factors are different for every seasonal (Yu et al., 2016), so temporal variation is crucial to study.

There are no black carbon studies in Malaysia, previous study only mentioned elemental and organic carbon. This study will be based line data. Other countries had monitored at their monitoring station, for example, Thuringia & Baden-Württemberg, Germany (Kutzner et. al, 2018), Guangzhou, South China (Chen et al., 2014), Makassar, Indonesia (Sattar et. al, 2014), Chungcheong Province, Korea (Cha, Lee and Lee, 2019), Metro Manila, Philippine (Alas et al., 2018), Northern Thailand (Chuang et al., 2016) and Singapore (Zhang et al., 2015). Transportation pollution is part of the major source that contributed to the black carbon aerosol concentration due to unfinished burning of fossil fuel from transportation (Cha, Lee, & Lee, 2019). Therefore, the real-time measurement of black carbon needs to be conducted in Malaysia to identify the spatio-temporal of black carbon concentration.

This study also wants to compare between day against night of spatio-temporal of black carbon in Klang Valley and compare black carbon aerosol concentration weekdays and weekend in urban (Kuala Lumpur) and suburban (Serdang). Thus, this study will be able to provide real time measurement of black carbon aerosol concentration in Klang Valley which can be used for further the studies of black carbon in Klang Valley and Malaysia.

1.4 Research Question

1. Is there any difference in BC aerosol concentration between urban (Kuala Lumpur) and suburban (Serdang)?
2. Is there any difference in the monthly and hourly variations of urban and suburban?
3. Is there any comparison between weekday and weekend of urban and suburban?
4. Is diurnal factor affecting the BC aerosol concentration in urban and suburban?

1.5 Research Objective

1.5.1 General Objective:

To assess the spatio-temporal of black carbon aerosol in Klang Valley.

1.5.2 Specific Objective:

There is four specific objectives in this study:

1. To determine the black carbon aerosol concentration between urban (Kuala Lumpur) and suburban (Serdang).
2. To determine the temporal factor of black carbon aerosol in urban and suburban.
3. To compare black carbon aerosol concentration weekdays and weekend in urban and suburban.
4. To compare between day against night of spatio-temporal of black carbon in urban and suburban.

1.6 Research Hypothesis

1. The average spatio-temporal of black carbon aerosol in urban (Kuala Lumpur) is higher compared to suburban (Serdang).
2. The black carbon aerosol concentration for weekdays is higher than weekends in urban and suburban.
3. The black carbon aerosol concentration for weekdays is significantly different from weekends in both urban and suburban.
4. There is a difference between day and night of spatio-temporal of black carbon aerosol concentration in Klang Valley.

1.7 Definition

1.7.1 Conceptual Definition

i. **Black Carbon**

Black carbon is viewed as the main light absorber and is radiated into the ambient air and correlate with soot by incomplete anthropogenic ignition and biomass combustion (Koike et al., 2014; Laskin et al.2015).

ii. **Traffic Pollutant**

Traffic emissions are highly heterogeneous, consisting of hundreds of organic and inorganic chemicals like PAH, polycyclic aromatic hydrocarbons; EC, elemental carbon; OC, organic carbon; WSOC, water-soluble organic carbon; BC, black carbon; Mg, magnesium; Al, aluminum; P, phosphorus; K, potassium; V, vanadium; Cr, chromium; Mn, manganese; Co, cobalt; Ni, nickel; Zn, zinc; As, arsenic; Cd, cadmium; Sb, antimony; Ba, barium; Ce, cerium and Pb, lead (Liang et al., 2019)

iii. **Particulate Matter**

Particulate matter brought into the air by natural and human activities in which it can be stay over long time and travel over long distances in the atmosphere and provide a lot of diseases that lead to a potential decrease of human lifespan (Kim, Kabir & Kabir et al., 2015)

1.7.2 Operational Definition

i. **Black Carbon**

Black carbon is measured using spectral measurements of the Aethalometer, the absorption coefficients were estimated by calculating the attenuation

(ATN) of the incident light due to which the particles placed on the quartz filter tape were determined and the BC intensity using the wavelength-dependent mass absorption cross-section (Ran et al., 2016).

ii. Traffic Pollutant

Traffic pollutant in urban and suburban is measured using Aethalometer AE33 (Magee Scientific, USA) in a continuous mode.

iii. Particulate Matter

Particulate matter is observed as the part of the contributor of black carbon (Klimont et al., 2017).

CHAPTER 2

LITERATURE REVIEW

2.1 Air Pollution and Black Carbon

Current outdoor air pollution accounts for 4.2 million premature deaths worldwide (GBD 2015 Risk Factors Collaborators, 2015), ranking within the top 10 most significant public health risk factor (Saenen et al., 2017). Black carbon is part of the key $PM_{2.5}$ portion emitted from diesel vehicles, coal, biomass stoves, and waste incineration (Klimont, 2017). Progressive increase in the use of fossil-fuel-powered vehicles becomes the key cause of air pollution which in turn poses a major risk to human health (Holgate, 2017). Other than that, in 2016 premature death worldwide caused by outdoor air pollution was estimated to be 4.2 million in both urban and rural areas (WHO, 2018). BC has greater impacts on cardiorespiratory morbidity and mortality than $PM_{2.5}$, which has a more heterogeneous chemical composition (Janssen et al., 2011). Although Black Carbon has effects not just on people's well-being, it has also appeared lately as a major contributing factor to climatic change (Lin et al. 2019). Besides, black carbon is a strong predictor of air pollution associated with combustion and has only recently been recognized as a short-lived climate force that helps to warm the Earth's atmosphere (Janssen et al., 2017)

2.2 Black Carbon: Composition, Source and Distribution

Black carbon is a carbonaceous aerosol material defined by light-absorbing measures (Luben et al., 2017). Carbonaceous aerosols are mainly fresh soot particles emitted from combustion sources are hydrophobic, water-insoluble, and remain unchanged in their structures (Rabha and Saikia, 2020). Black carbon composition is present in submicron particles (Kirrane et al., 2019). Black carbon exhibit a lot more within-city inclination compared to rural gradients of PM2.5, particularly in territories with high volumes of on-street sources (Luben, 2017). Furthermore, black carbon is viewed as the main light absorber and is radiated into the ambient air and correlate with soot by incomplete anthropogenic ignition and biomass combustion (Koike et al., 2014; Laskin et al., 2015). According to Cai et al. (2013) specific marker of primary combustion for vehicle and biomass emission is black carbon (BC). Sattar et. al, 2014 stated that automobile emissions from transportation is the main source of black carbon in the cities area. Biomass burning transmits large measures of short-term global warming components (Victor et al., 2015) for example, black carbon, fundamentally adds to ozone development by photochemical responses among its for runner of VOCs and NOx (Jianmin et. al, 2017).

2.3 Black Carbon: Health Impact

Black carbon (BC) is an inescapable particulate matter (PM) component generated from sources associated with combustion and is correlated with several health outcomes (Luben et al., 2017). BC is small enough for a quick intake of inhalation into the lungs and has been linked with adverse health effects (USEPA, n.d).

Black carbon less than 0.1 μm can enter the human body via diffusion through the pulmonary tract and infiltrate vital organs like the brain (Kim, Kim & Lee, 2019) Since BC efficiently enters human lung tissue, it causes serious health effects, such as oxidative injury, and increases pulmonary discomfort symptoms (Lin et al., 2015). Long-term exposure to BC can increase the risk of mortality related to cardiovascular diseases (Baumgartner et al., 2014). Several past studies that examined the health impact of black carbon can be seen in Table 2.1, where the BC was associated with health impacts of chronic obstructive pulmonary disease, type 2 diabetes, coronary artery disease, and cardiovascular disease.

Table 2.1: Previous studies on the health impact of black carbon

Study	Location	Health impact	Black carbon value (μg/m^3)
Suh et al. 2011	Atlanta, Georgia	Chronic obstructive pulmonary disease	1.2
Rich et al. 2016	Rochester, New York	Type 2 diabetes	0.5
Zanobetti et al. 2010	Boston, Massachusetts	Coronary arteries disease	0.6
Kim et al. 2015	Denver, Colorado	Cardiovascular disease	0.33
Geng et al. 2013	Shanghai, China	Cardiovascular disease	2.7
Huang et al. 2012	Xi'an, China	Cardiovascular disease	6.6

2.4 Black Carbon: Climate Change

Although not only does black carbon have effects on human wellbeing, it has also currently, black carbon has emerged as a significant contributor to climate change that absorbs incoming short-wave solar radiation in the troposphere, consumes outgoing long-wave terrestrial radiation at the same time and thus retains heat. (Lin et al. 2019). As BC warming the atmosphere, it affecting the earth's radiation balance on a global scale (Shindell et al., 2012). Global warming is stated to be closely related to black carbon concentration (Cha, Lee & Lee, 2019). BC was deemed the second largest human-induced contributor to climate change, equal to 55 percent of CO_2-induced radiative forcing, and nearly doubled that of methane (Subba et al., 2018).

Shindell and Faluvegi (2009) stated that the Arctic temperature has risen faster than the global average over the last century. Anticipated by warming, the Arctic encountered rapid melting, including a substantial decrease in the extent of sea ice, decreased snow cover, and extreme melting across the surface of the Greenland ice cap (Bokhorst et al., 2016). In the Arctic, the reflective surface of snow and ice makes it a very vulnerable area for aerosols (Chen, Kang & Yang, 2020). Other than that, as a light-absorbing aerosol, BC has strong influences on temperature increase in the Arctic (Bond et al., 2013; Flanner, 2013). The deposition of BC on snow and ice could lead to increased melting in the Arctic, further affecting regional and global climate (Namazi et al., 2015). Therefore, to minimize BC's take-up on climate change, it is important to more clearly identify the origins of BC.

2.5 Black Carbon Measurement across the Region

As black carbon plays an important role in contributing to the health impact and climate change several countries across the region have done studied and measuring black carbon regularly. Table 2.2 shows several previous studies that have been done to study black carbon. Previous studies on BC real-time measurements are compiled in the table below in other parts of the world. However, none of the studies for BC measured in real-time is a study in Malaysia except for a local study collected BC in the traditional filter method by Amil et al. (2016) in Klang Valley, Malaysia. Each of the studies stated in Table 2.2 focus their sampling on urban, traffic site, industrial commercial, and roadside as the main contributor to black carbon aerosol concentration is the vehicle emission and biomass burning. Most of the BC in urban and high traffic density areas showed higher BC concentration with more than 2 $\mu g/m^3$ compared to rural and remote measurement areas with less than 2 $\mu g/m^3$.

Table 2.2: Previous study on black carbon measurement

Study	Location	Measurement area	Average value of black carbon ($\mu g/m^3$)
Kutzner et. al, 2018	Thuringia & Baden-Württemberg , Germany	traffic site	5.4
		urban background	2.1
		industrial	2.2
		rural	1.6
Chen et. al,2014	Guangzhou, South China	urban	4.7

Sattar et. al, 2014	Makassar, Indonesia	mixed urban, commercial and industrial	2.0
(Cha, Lee & Lee, 2019).	Chungcheong Province, Korea	urban	1.4 (Fall 2015) 1.6 (Winter 2015) 2.3 (Spring 2016)
Alas et al., 2018	Metro Manila, Philipines	Urban Roadside	7.0 ± 4.8 16.5 ± 11.7
Chuang et al., 2016	Northern Thailand	Sea	4.4 ± 2.6
Zhang et al., 2015	Singapore	Urban (School)	3.3 (± 0.174)
Khan et al., 2018	Lake Hoare Camp, Miers Valley Alatna Valley Mt. Fleming	Urban Remote	0.001 0.0013 0.00011 0.00009
Amil et al., 2016	Klang Valley, Malaysia	Urban	4.2

2.6 Black Carbon: Spatio-Temporal Factor

Considerable efforts are underway to estimate black carbon on a global/regional scale, but uncertainties in observations and simulations remain, particularly regarding the concentrations and spatiotemporal distributions of black carbon (Gertler et al., 2016; Gustafsson and Ramanathan, 2016; Ji et al., 2015; Qian et al., 2015). Since the sources are highly variable across different parts of the world, (Rajesh and Ramachandran, 2017) the concentrations of BC will be highly regional based and will vary temporarily depending on the level of industrialization, transport volume, and energy consumption in households for electricity production and cooking activities (Ramachandran and Rajesh, 2007). The widespread presence and large variability of BC also call for BC observations with high spatiotemporal resolution (Deng et al., 2020). Therefore, understanding the current BC sources as well as their spatial and diurnal variations would help decision-makers to implement more effective regulatory programs to further reduce the emissions of BC (Mousavi et al., 2018). Other than that, observing the spatio-temporal pattern of BC can likely present the true pollution in the field (Awad et al., 2017). The investigation of the temporal variation of BC absorption properties were also crucial in the identification of the local and long-range BC emission sources at the observational site under study (Kolhe et al., 2019).

2.7 Aethelometer as an Equipment for Black Carbon Measurement

GAINS model estimate (Greenhouse gas - Air Pollution Interaction System) for 2015 show that global BC from fossil fuel sources such as transportation and household burning is 24% and 58% respectively (Klimont, 2017). However, these percentages change dramatically at the regional level; thus, identifying BC sources is critical for the development and deployment of mitigation strategies (Kiran et al., 2019).

There are generally different methods/strategies for identifying BC sources. Reliable and clear approaches are based on thermo-optical techniques such as EC / OC analyzer, radiocarbon isotope (14C) (Martinsson et al., 2017; Zotter et al., 2017). But certain practices take time (Kiran et al., 2019). Source estimates are given by information from ASM (real-time aerosol specification) combined with analytical methods such as Positive Matrix Factorization (PMF) and Multilinear Engine (ME-2) (Crippa et al. 2013; Zhang et al., 2018). These instruments, however, are costly, and uncertain analytical methods (Kiran et al., 2019).

Source allocation methods based on optical BC calculation are fairly easy to implement as compared to others (Kiran et al., 2019). Using spectral measurements of the Aethalometer, the absorption coefficients were estimated by calculating the attenuation (ATN) of the incident light due to which the particles placed on the quartz filter tape were determined and the BC intensity using the wavelength-dependent mass absorption cross section (Ran et al., 2016). This model was subsequently extended and verified by multiple researchers (Becerril-Valle et al., 2017; Dumka et al., 2018; Healy et al., 2017; Helin et al., 2018; Liu et al., 2018b; Martinsson et al., 2017; Mousavi et al., 2018; Zotter et al., 2017).

In this study, a dual spot Aethalometer (AE33, Magee Scientific) was used. The light attenuation was measured at seven wavelengths (370, 470, 520, 590, 660, 880 and 950 nm) concurrently at two separate sample spots on the filter film, where the production from both samples was calculated and used to estimate the corrected aerosol light attenuation that can provide real-time BC mass concentrations (Drinovec et al., 2015). The benefit of using dual spot approach prevents manual post-processing of data that needs to be performed to account for the loading effect of the filter (Drinovec et al., 2015, Petit et al., 2015)

CHAPTER 3

METHODOLOGY

3.1 Study Design

This study aims to assess the spatio-temporal of black carbon aerosol in urban and suburban of Klang Valley, Malaysia. The location of the study was selected from urban and sub-urban areas with high and low traffic density in Klang Valley. This research focused on trend of black carbon aerosol with determination in the aspects of time and places.

3.2 Sampling Site

The assessment involves two areas which was urban and suburban in Klang Valley which at Faculty of Medicine and Health Sciences (FMHS), University Putra Malaysia (UPM), Serdang (2.9998° N, 101.7121° E) (suburban) as shown in Figure 3.1, which located near Hospital Serdang road and the nearest highway identified was South Klang Valley Expressway (SKVE) where this faculty was surrounded by private forest property of UPM, Hospital Serdang, Faculty Of Veterinary and Hospital of Teaching, UPM. It also has commercials buildings near the sampling site which was malls, hotel, offices, houses, and research institutes (MAEPS).

Figure 3.1: Sampling Station at Faculty of Medicine and Health Sciences, UPM

For the second area that covered in this study was at the Faculty of Sciences (FS), University of Malaya (UM), Kuala Lumpur (3.1220° N, 101.6546° E) (urban) as shown in Figure 3.2, located near "Lingkungan Budi" road where it was surrounded by private forest property of UM, Institute of Biological Sciences, High Impact Research Building and Faculty of Arts and Social Sciences. Near to the "Lingkungan Budi" road also have the main library of University Malaya, Post Office, Experimental Theatre, and "Dewan Tunku Canselor". For both this area, they were the main attraction for a lot of people to come and lead to traffic congestion which was suitable to do the measurement of black carbon.

Figure 3.2: Sampling Station at Faculty of Sciences, UM

3.3 Instrument

The instrument that was used to measure and collect black carbon was Aethalometer Model AE33 (Magee Scientific, USA) from Enviro Exceltech Sdn Bhd. Aethalometer is a direct measurement of airborne on the filter with a concurrent capacity of decrease of transmitted light at frequencies of 370, 470, 520, 590, 660, 880 and 950 nm, where the black carbon mass measurement will be taken up from absorption measurement at 880 nm (Magee, 2017). The pump of Aethalometer AE-33 works with a steady wind current pace of around 5 L/min and a twenty-four hour sampling time goal of 1 min.

Figure 3.3: Aethalometer® Model AE33 (AE33)

3.4 Data Collection

The monitoring equipment of black carbon, Aethalometer Model AE33 (Magee scientific, USA) was placed on the rooftop and left for three months at both of the places where the instrument was left first at urban (Kuala Lumpur, UM) from the end of July 2019 until early of October 2020 and then the equipment was left at suburban (Serdang, UPM) on early December 2019 until end of February 2020. The AE33 was calibrated every six months and a new filter was fitted before each of the placement made by the loan company by following the instruction manual of the equipment. The data that been saved in the equipment was taken two times per week. Data saved in the AE33 was exported into the USB memory device from the USB ports on the front panel door by selecting the period that is required. Then, the data was transferred to the computer. Additionally in this study, all data were checked for the robustness of the dataset, to detect anomalous records, for irregular, zero, negative values and single extreme measurements were excluded by manual observations for data quality control.

3.5 Data Analysis

The data that is collected will be analysed using Microsoft Excel 2013 for descriptive statistic and Statistical Package for the Social Sciences (SPSS) version 25.0 was used for the independent t-test.

Statistical analysis of descriptive analysis was used to determine the baseline level of spatio-temporal of black carbon aerosol in campus site in urban (Kuala Lumpur) and suburban (Serdang) that includes the average, standard deviation, maximum value, and minimum value. Microsoft Excel was also used to determine the temporal variation of black carbon aerosol in Klang Valley which include monthly, hourly, diurnal, and weekends and weekdays. While independent t-test was to compare the black carbon aerosol concentration weekdays and weekends; day and night time between urban (Kuala Lumpur) and suburban (Serdang).

CHAPTER 4

RESULT

4.1 Summary of Black Carbon Aerosol Concentration in Urban (Kuala Lumpur) Site (July 2019- Oct 2019) and Suburban (Serdang) Site (Dec 2019 -Feb 2020).

Summary distribution of black carbon aerosol concentration collected for the urban site from July 2019 to October 2019 and suburban site from December 2019 until February 2020 have been shown in Table 4.1. Out of the two background locations, the highest in black carbon aerosol concentration was observed at urban site, having a maximum average concentration of 12.4 µg/m^3 which shown 1.4 times higher compared to suburban site and having an average minimum concentration of 0.4 µg/m^3 with slight difference of 0.2 µg/m^3 higher compared to suburban site. Both urban and suburban site showed low standard deviation which indicates that the dispersion of data is closed to the mean of black carbon concentration for each of the site.

Table 4.1: Descriptive statistics of Black Carbon concentration measured by real-time monitors in different study periods and sampling locations. All data represent the mean of recorded average 1-min observation.

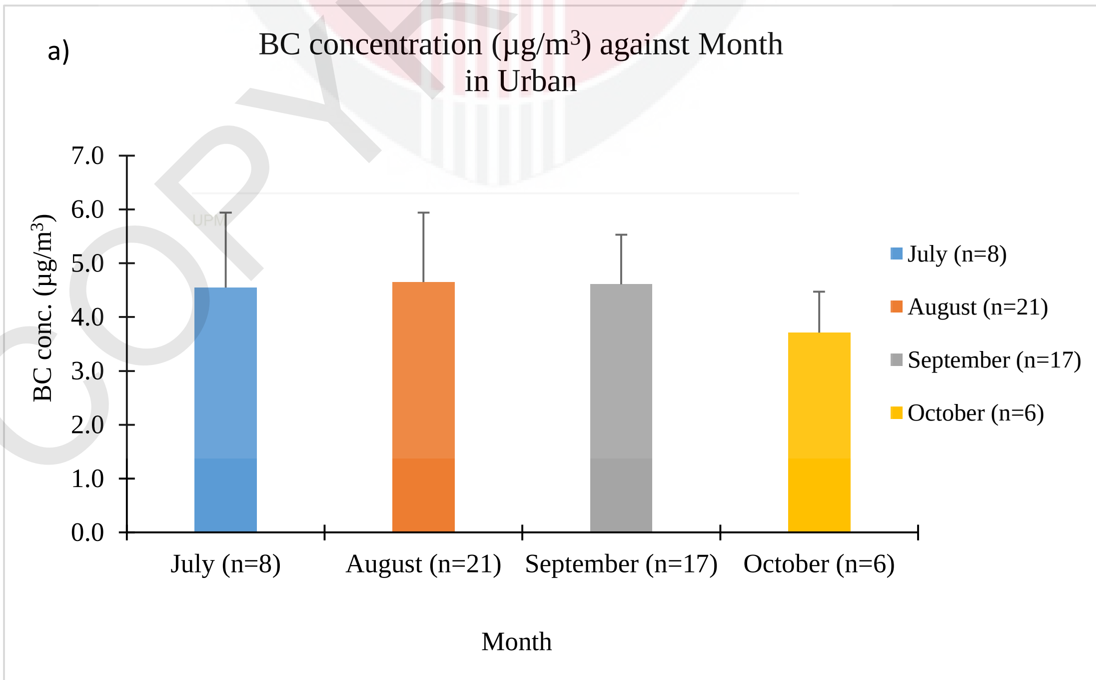
Location	Study Period	Mean ± SD (µg/m^3)	Max (µg/m^3)	Min (µg/m^3)
Urban (n=52)	24/7/2019 – 6/10/2019	4.5 ± 1.9	12.4	0.4

Suburban (n=83)	7/12/2019 – 29/2/2020	2.5 ± 1.5	8.9	0.2

4.2 Temporal Variations of BC in the Urban and Suburban

4.2.1 Monthly Variation of BC in Klang Valley

Further analysis of several month data is depicted in Figure 4.1 for two different sites. From Figure 4.1(a), it could be interpreted that around July until September 2019 in urban show higher average BC concentration in the range of 4.5-4.6 µg/m^3 compared to October with 3.7 µg/m^3. While for the suburban site, December 2019 show the highest average BC concentration with 3.1 µg/m^3 compared to January and February 2020 (Figure 4.1(b)).



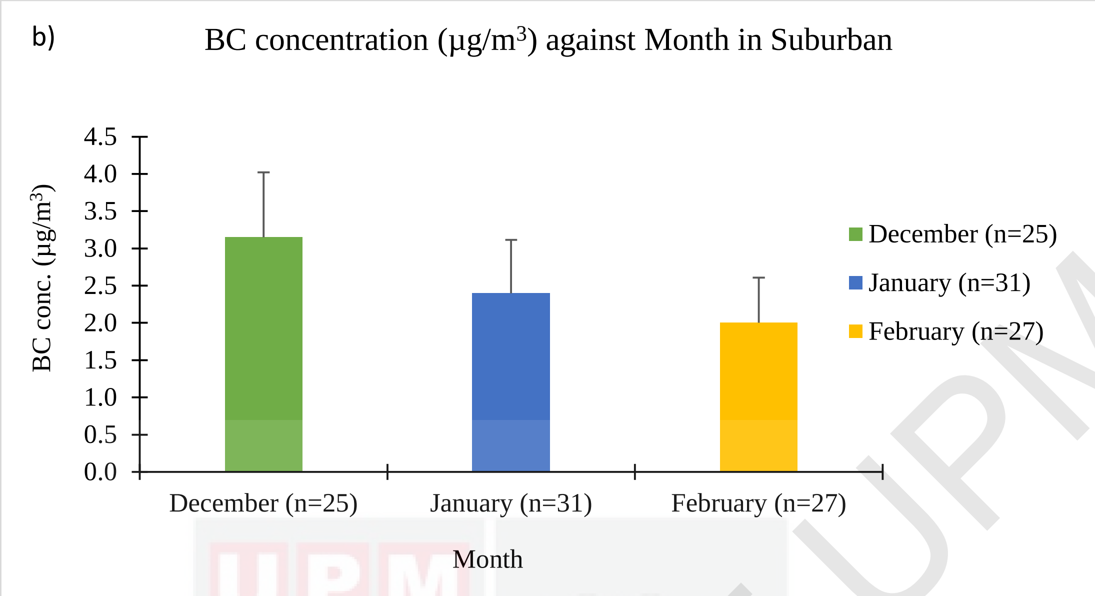


Figure 4.1: Observed average of BC concentrations (µg/m³) with standard deviation whisker at (a) Urban site and (b) Suburban site. The numbers in the bracket show the number of days sample each month.

4.2.2 Hourly Variation of BC in Klang Valley

Similar hourly variation pattern was observed at both urban and suburban locations with peaks observed at around 8-9 a.m. in the range of 6.7-7.3 µg/m³ and 3.4-4.3 µg/m³ respectively while minimum concentration was observed during the afternoon at around 1 until 3 p.m. for each month with urban site in the range 2.3-3.5 µg/m³ and suburban in the range of 1.2-1.7 µg/m³ (Figure 4.2). The range of maximum concentration observed varied largely from 7.3 µg/m³ in July to October 2019 with 5.4 µg/m³ at urban site (Figure 4.2 (a)). For suburban sites, the range of maximum concentration observed varied largely in December 2019 from 4.3 µg/m³ to 3.4 µg/m³ in February (Figure 4.2(b)).

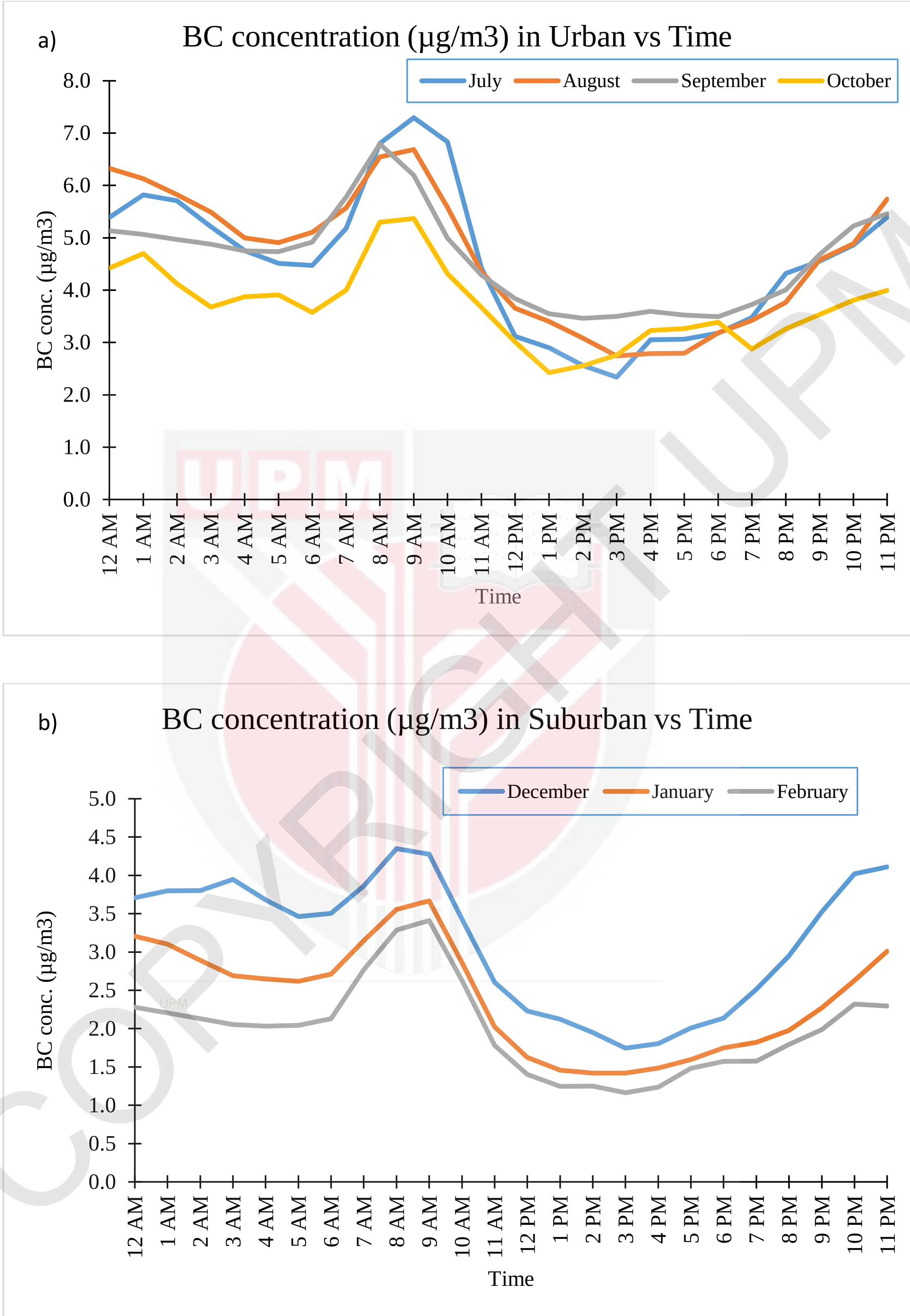


Figure 4.2: Observed hourly average of BC concentration at (a) urban site and (b) suburban site.

4.3 Comparison of Weekday with Weekend BC Aerosol Concentration

4.3.1 Summary Mean of Weekday and Weekend of BC for Urban (Kuala Lumpur) and Suburban (Serdang)

The daily average of BC concentration for each day of a week was averaged for the duration of 2019-2020 (Table 4.2) of each location. For urban, the highest days in weekday was on Tuesday, Wednesday and Thursday where the mean was in the range of 4.9 – 5.0µg/m^3, while for suburban the highest days in weekday was observed on Tuesday and Wednesday with a mean range of 2.8 – 2.9 µg/m^3 (Table 4.2). From Table 4.2, it can be also depicted that at urban site the maximum BC concentration shows a decline of 26% which from 12.4 µg/m^3 on Tuesday to 9.2 µg/m^3 on Sunday. While for suburban site it was observed that the maximum BC concentration shows a mild difference of 1.68 µg/m^3 between weekday and weekend which could be due to less use of vehicles in the suburban site. For both of the assessment site, BC measurement on weekend shows highest on Saturday with urban site (4.9 $\pm$ 0.9 µg/m^3) and suburban site (2.7 $\pm$ 1.2 µg/m^3). The minimum BC measurement for urban and suburban was found on Wednesday of weekday 0.4 µg/m^3 and 0.2 µg/m^3 respectively and Sunday of the weekend with 0.8 µg/m^3 and 0.3 µg/m^3 respectively.

Table 4.2: Descriptive Statistic of BC Concentration for Weekday and Weekend in Urban (Kuala Lumpur) and Suburban (Serdang) on Different Day.

BC Measurements	Urban			Suburban		
	Mean $\pm$ SD (µg/m^3)	Max (µg/m^3)	Min (µg/m^3)	Mean $\pm$ SD (µg/m^3)	Max (µg/m^3)	Min (µg/m^3)
Weekday	4.7 $\pm$ 1.1	12.4	0.4	2.6 $\pm$ 0.8	8.9	0.2
Monday	3.9 $\pm$ 0.3	8.1	1.5	2.3 $\pm$ 0.7	7.9	0.4
Tuesday	4.9 $\pm$ 1.2	12.4	1.1	2.9 $\pm$ 1.0	8.9	0.4
Wednesday	4.9 $\pm$ 0.7	11.3	0.4	2.3 $\pm$ 0.9	8.0	0.2
Thursday	5.0 $\pm$ 0.7	9.9	1.2	2.6 $\pm$ 0.7	7.6	0.5
Friday	4.3 $\pm$ 0.9	9.5	0.8	2.8 $\pm$ 1.0	8.5	0.3
Weekend	4.5 $\pm$ 1.2	10.8	0.8	2.3 $\pm$ 0.7	8.7	0.3
Saturday	4.9 $\pm$ 0.9	10.8	1.8	2.7 $\pm$ 1.2	8.7	0.5
Sunday	3.5 $\pm$ 1.1	9.2	0.8	1.9 $\pm$ 0.8	7.3	0.3

4.3.2 Relationship between Weekday and Weekend in Urban and Suburban

Urban measurement for weekdays' (4.7 $\pm$ 1.1 µg/m^3) and weekdays' (4.5 $\pm$ 1.2 µg/m^3) BC measurement were normally distributed, but there was substantially more variance in weekdays BC measurement. Consequently, an independent t-test was used to compare the weekday's BC measurement with the weekend's BC measurement. Based on Table 4.3, the t-test was found not significant, t (38) = 0.4, p = 0.7 (p >0.05), which shows there was no significant difference between weekday and weekend of urban.

Independent t-test was also used to compare the mean of weekdays' (2.6 ± 0.8 µg/m^3) and weekends' (2.3 ± 0.7 µg/m^3) of suburban site where both weekday and weekend were normally distributed, but there was more variance of weekdays BC measurement. According to Table 4.3, there was no significant difference between weekday and weekend of suburban, the t-test was not significant with t (46) = 1.1, p = 0.3 (p>0.05).

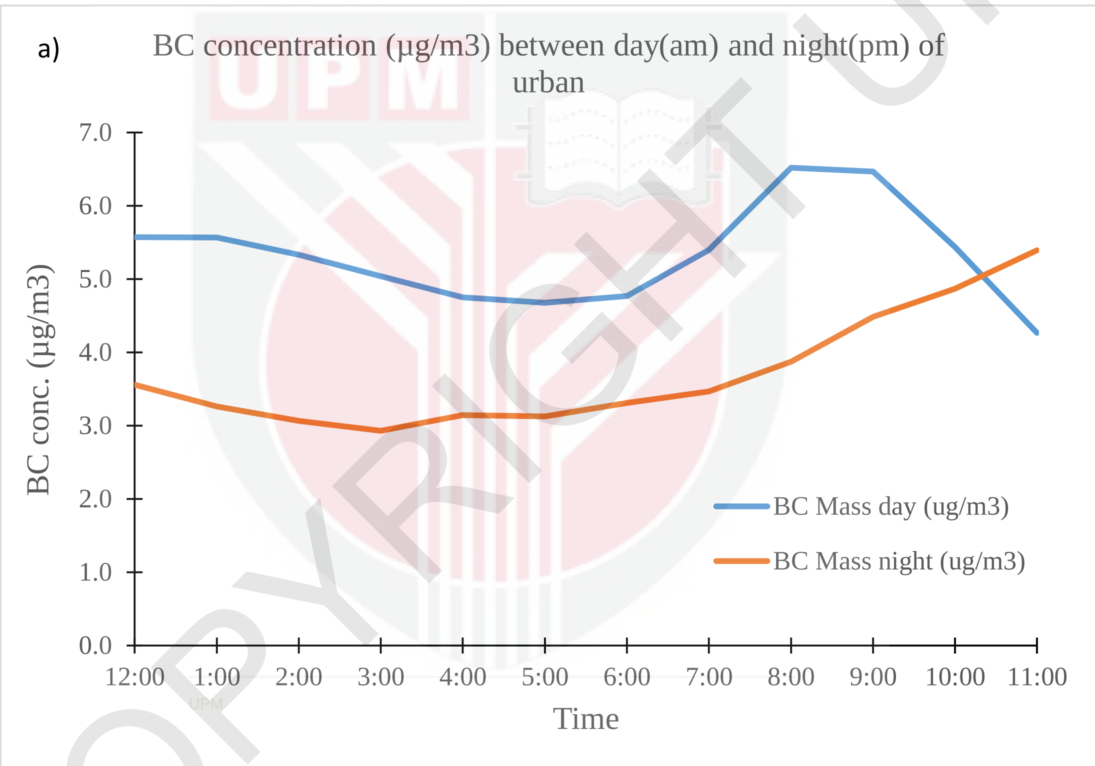
Table 4.3: Comparison of weekday and weekend BC measurement for urban and suburban (N=48).

BC measurement	Mean ± SD (µg/m^3)	95% C.I	t	p
Urban				
Weekday	4.7 ± 1.1	-0.6 – 0.9	0.4	0.7
Weekend	4.5 ± 1.2	-0.6 – 0.9		
Suburban				
Weekday	2.6 ± 0.8	-0.1 – 0.6	1.1	0.3
Weekend	2.3 ± 0.7	-0.1 – 0.6		

4.4 Comparison of BC Diurnal Variations

4.4.1 Summary Mean of Day and Night of BC for Urban and Suburban

Diurnal variation of black carbon aerosol in urban and suburban have also been observed and shown in Figure 4.3 and Table 4.4. The diurnal variation that been observed from continuous measurements of AE33 was separated into day (from 12 am until 11 am) and night (from 12 pm until 11 pm). Figure 4.3 urban and suburban showed the peak and minimum of day and night showed the same time as in weekday and weekend. Overall according to Table 4.4, diurnal BC measurement for urban and suburban sites, both showed average BC measurement during the day was higher compared to average BC measurement during the night where the average day for both urban and suburban was 1.4 and 1.5 times higher respectively. From Table 4.4, the diurnal pattern was observed that urban site show higher BC concentration for day and night with 1.8 and 1.9 times higher than diurnal for suburban.



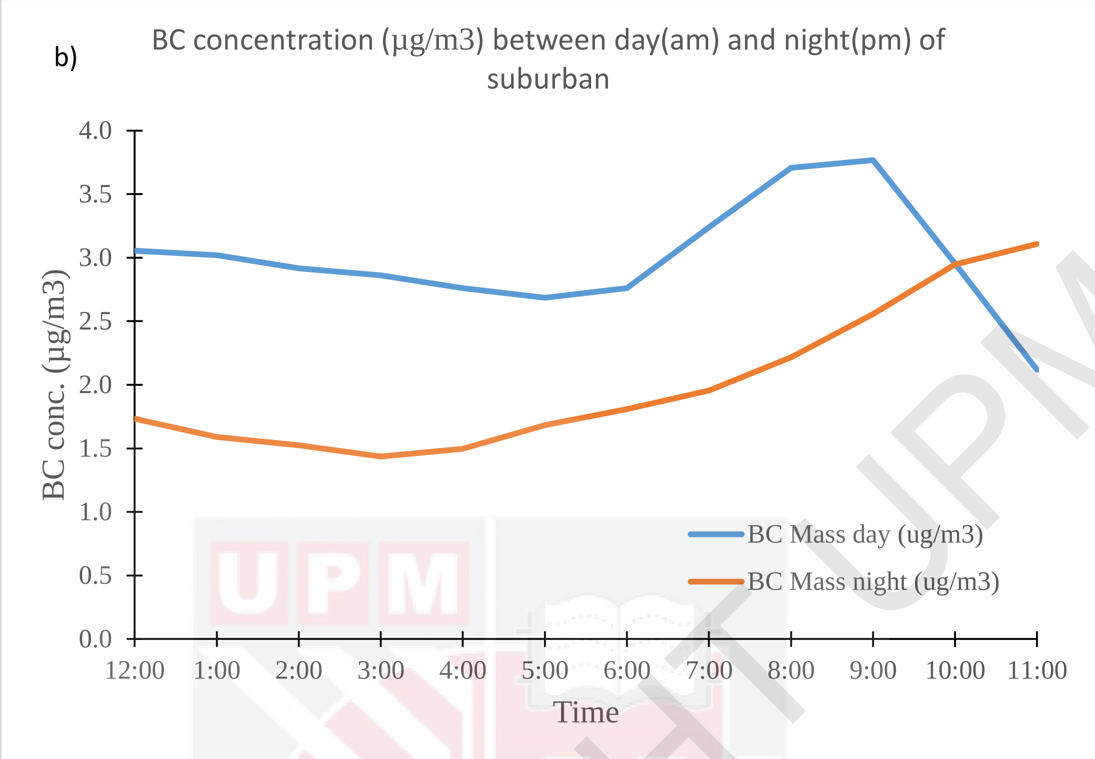


Figure 4.3: Observed hourly average day and night of BC concentration at (a) Urban site and (b) Suburban site

Table 4.4: Descriptive statistics of black carbon concentration for diurnal variation.

BC Measurements	Urban			Suburban		
	Mean ± SD ($\mu g/m^3$)	Max ($\mu g/m^3$)	Min ($\mu g/m^3$)	Mean ± SD ($\mu g/m^3$)	Max ($\mu g/m^3$)	Min ($\mu g/m^3$)
Day (12am-11am)	5.3 ± 0.7	6.5	4.3	3.0 ± 0.4	3.8	2.1
Night (12pm-11pm)	3.7 ± 0.8	5.4	2.9	2.0 ± 0.6	3.1	1.4

4.4.2 Relationship between Day and Night time

Urban site for the day (5.3 $\pm$ 0.7 µg/m^3) and night (3.7 $\pm$ 0.8 µg/m^3) BC measurement were normally distributed, but there was substantially more variance in day BC measurement. Consequently, an independent t-test was used to compare the day BC measurement with night BC measurement. Based on Table 4.5, the t-test was found a significant, t (22) = 5.3, p = 0.00 (p <0.05), which show there was significant difference between weekday and weekend of urban.

Independent t-test was also used to compare the mean of days' (3.0 $\pm$ 0.4 µg/m^3) and nights' (2.0 $\pm$ 0.6 µg/m^3) of suburban site where both day and night were normally distributed, but there was more variance of day BC measurement. According to Table 4.5, there was a significant difference between weekday and weekend of suburban, the t-test was significant with t (22) = 4.8, p = 0.00 (p<0.05).

Table 4.5: Relationship of day and night BC measurement for urban and suburban (N=48).

BC measurement	Mean $\pm$ SD (µg/m^3)	95% C.I	t	p
Urban				
Day	5.3 $\pm$ 0.7	1.6– 0.3	5.3	0.00
Night	3.7 $\pm$ 0.8	1.6– 0.3		
Suburban				
Day	3.0 $\pm$ 0.4	0.6-1.4	4.8	0.00
Night	2.0 $\pm$ 0.6	0.6-1.4		

CHAPTER 5

DISCUSSION

5.1 Spatial Distribution of Black Carbon (BC) Aerosol Concentration.

The result showed that out of the urban and suburban background location, the highest in average black carbon aerosol concentration was observed at urban (Kuala Lumpur) site (4.5 $\pm$ 1.9 µg/m^3) which has 1.8 times higher compared to average black carbon aerosol concentration of suburban site (Serdang) (2.5 $\pm$ 1.5 µg/m^3). The differences average of black carbon aerosol concentration between the two locations might be influenced by the distance of busy road from sampling site (geographical factor), where Kuala Lumpur site located nearer to the main busy road ('Lingkungan Budi') compared to Serdang site as the instrument was placed in a building that not too near the busy road (Hospital Serdang road) and the nearest highway South Klang Valley Expressway (SKVE) was blocked by the forest in between the instrument and highway road. In a study by Hankey and Marshall (2015) they found that concentrations of particle number and BC were correlated with the street type and declined approximately 20% by moving within small distances from a major road to adjacent local roads in Minneapolis. Furthermore, the city's geographical features impact local airflows and, ultimately, the concentration of pollutants within the urban canopy layer (Krecl et al., 2015, Boddy et al., 2005).

5.2 Temporal Variation of Black Carbon (BC) Aerosol Concentration in Klang Valley

The average of black carbon aerosol concentration in urban was the highest (4.5-3.7 µg/m^3) during the month of July 2019 until October 2019 compared to suburban having lower BC aerosol concentration in the range of 3.1 – 2.0 µg/m^3 (December 2019 – February 2020). These differences were influenced by the season of haze that happens in Malaysia (from July until October 2019). This finding is supported by a study which has been done in Bejing which an average BC concentration during a severe haze episode in January 2013 (7.6 ± 4.8 µg m^{-3}) is 2.5 times greater than on clear days (2.0 ± 1.2 µg m^{-3}) (Liu et. al, 2016). According to the Malaysian Meteorological Department haze episode usually occur from June until August every year. While for the year of 2019 in 'Sinar Harian' newspaper Malaysian Meteorological Department stated that Malaysia will face haze episodes start on 31st July 2019 due to forest and land fire in Sumatera, Indonesia which was help by the movement of wind (Southeast Monsoon) (Ismail, 2019). The haze episode was expected to end in early October 2019 (Sidi, 2019).

Black carbon aerosol concentration in urban can be affected by the Southwest Monsoon due to period of assessment in month July until October 2019, where during this monsoon there will be less cloud formation which causes the weather to become dry and will increase the concentration of BC aerosol as there is no rain to remove the BC from the atmosphere. This can be supported by a study in Kadapa, India; the BC concentration showed a correlation coefficient of -0.79 against the rainfall, as the rainfall increase, BC concentration decreased (Begam et al., 2016). However, some study finds that wet scavenging by rain is relatively inefficient as the vast majority of the BC mass (95 %) was enclosed in the range of 0.1–1 μm; are too large to diffuse efficiently and too small to impact (Seinfeld and Pandis, 2016; Cruz et al., 2019). Black carbon concentrations were not only associated with the weather patterns but also affected by the local wind speed and planetary boundary layer (PBL) height (Tie et al., 2015). Similarly, the black carbon concentration was higher during the dry months which may be attributed to rampant biomass burning during hot and dry weather conditions, apart contributions from other possible sources (Sattar et al., 2014).

Descriptive analysis for hourly variation pattern was observed that both urban and suburban locations have similar peaks time observed in the morning at around 8-9 a.m. and gradual decrease with minimum BC concentration during the afternoon at around 1 until 3 p.m. for each of the months. Morning peak BC concentration was found corresponding to the time with rush hour traffic between 7 a.m until 10 a.m. (Boniardi et al., 2019). For the weekday BC concentration in urban and suburban both showed 1.0 and 1.1 times higher compared to the weekend BC concentration respectively. This showed that there was more vehicle emission on weekdays compared to weekends. This presumable is similar to study in Rubidoux, California where the BC mass concentration was higher on weekdays than weekends, due to weekday increases in traffic emission (Krasowsky et al., 2016).

Diurnal variation of black carbon aerosol in urban (Kuala Lumpur) and suburban (Serdang) have also been observed, overall according to Table 4.4, both showed average BC aerosol concentration measurement during day was higher compared to average BC measurement during night where the average day for both urban and suburban was 5.3 $\pm$ 0.7 μg/m^3 and 3.0 $\pm$ 0.4 μg/m^3 respectively this could be due to more use of vehicles in the day from working people and student in area

Kuala Lumpur (UM) and Serdang (UPM). Some study shows that the high daytime BC concentration is due to the prevalence of high traffic and biomass emissions during the day time of the month (Bhat, Romshoo & Beig, 2017).

CHAPTER 6

CONCLUSION

6.1 Overall Summary

This is the first study of real-time data of BC aerosol concentration for two locations in the Klang Valley from July 2019 until October 2019 for urban (Kuala Lumpur) and from December 2019 until February 2020 for suburban (Serdang). In this study, we evaluated the spatial and temporal variations of BC concentration. Our result indicated that higher BC aerosol concentration was found in urban (4.5 $\pm$ 1.9 µg/m^3) compared to suburban (2.5 $\pm$ 1.5 µg/m^3) due to the presence of haze episode and the dry season from Southwest monsoon wind that involved the month of late July and early October 2019 which help the increase of BC aerosol concentration. Hence, it is derived that occasional impact isn't eclipsed by high vehicular emanation. However, other factors like distance of sources to the instrument and number of the vehicle passing through should also be considered to know exactly the main contributor for the variation of BC concentration.

The analysis of temporal variation also revealed that BC aerosol show decreased in maximum average BC concentration throughout the month of sampling from July 2019 to October 2019 with 1.9 µg/m^3 at the urban site while for suburban site, the range of maximum average concentration observed varied slightly difference of 0.9 µg/m^3 in December 2019 to February 2020. We also observed higher average concentration in both sampling sites for daytime (5.3 and 3.0 µg/m^3) and weekday (4.7 and 2.6 µg/m^3) due to the contribution of vehicular emission which is the major source of BC concentration.

Hourly variation showed a high average of BC concentration during the morning (8-9a.m) and low average of BC concentration was observed during the afternoon (1-3 p.m) due to rush hour in the morning. While for diurnal variation, both showed average BC measurement during day was higher compared to average BC measurement during night where the average day for both urban and suburban was 1.4 and 1.5 times higher respectively.

6.2 Study Limitation

In this study, there is still a lack of information on the number of cars and the accurate distance count from the source to the BC concentration instrument. These two play a big role in determining the reason of a sampling place to be high in BC concentration. Another limitation of this study is the lack of emission factors from vehicle and biomass burning sources. These can be embedded into source apportionment investigation to be done in the future. Other than that, it was also identified this study lack of information on meteorological parameter, for example, wind speed, rainfall day count, temperature, and humidity. This data is needed to support finding that can be correlated with the meteorological study. Even though this study has some limitations but it can help provide based line data for further study on black carbon aerosol concentration in Malaysia.

6.3 Recommendation

Black carbon is part of an important factor to estimate air pollution by the release of traffic emission and biomass burning so an understanding of the real situation emission of BC is vital for future study. Other than that, the future study also needs to consider various meteorological conditions and other characteristics including the mixing processes and mixing states between BC and other aerosols. Comparison with other particulates pollutant concentrations such as $PM_{2.5}$ and gaseous measurements (NO_2) are necessary for future study. Long term study of spatio-temporal trends of BC concentration in air pollution is crucial to identify the more prominent sources of BC in Malaysia and addressing the health effects affected.

In the authors' opinion policymakers and environmental management is to consider the dominant BC source emission to identify whether to reduce light or heavy-duty vehicle on the road. Other than that, the policymakers and environmental management must ensure that the new vehicle entering the market follow the emission standard accordingly. They also can provide research on more efficient and cleaner vehicle as this will the car manufacturers to comply with the emission standard.

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