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Black Carbon and Traffic-Related PM2.5 in Bangkok Area

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Abstract. This study was to investigate level of black carbon (BC) in urban areas of Bangkok, Thailand. Hourly BC concentrations were measured at two stations (operated by PCD), i.e., Bangna station and Thonburi station (roadside) during dry season by using the aethalometer (Model AE-42). The averages of hourly BC concentrations observed were 5.1±2.9 and 4.3±1.9 µg/m3, respectively. The diurnal pattern of BC levels obtained from two stations exhibited two peaks of BC concentrations occurring in the morning (0500 to 0800 LST) and late evening (2100 to 2300 LST), which the late evening peaks were higher than the morning ones. The morning peaks of BC were evidently influenced by traffic condition, while the evening peaks were possibly related to traffic associated with meteorological effects. BC concentrations from roadside stations (Thonburi) were higher than those from Bangna station possibly due to less distance of sampling equipment from roads. There was some difference of BC concentrations observed between during weekday and weekends, particularly, at roadside station (Thonburi station). In addition, increase of diesel vehicles proportion, particularly in the nighttime, contributed to higher BC concentrations. The relationships among BC concentration, air pollutants (PM2.5), vehicle fleets and meteorological variables were found.

1 Introduction

Vehicle emissions are typically the largest contributors to air pollution exposure in urban environments. In Asian developing countries, the increase in vehicles causing traffic congestion, coupled with limited expansion of road surface areas, poor vehicle maintenance, and low fuel quality, poses a significant threat to urban air quality and the well-being of the population. Traffic sources emit the majority of particulate matter, including PM2.5 (particulate matter less than 2.5 micrometres in aerodynamic diameter) and PM10 (particulate matter less than 10 micrometres in aerodynamic diameter), nitrogen oxides (NOx), carbon monoxide (CO) and non-methane hydrocarbons (HC).

Particulate matter (PM) is regarded as the principal air pollutant in urban areas. PM emitted directly from road vehicles has a wide range of particle sizes, including ultrafine, fine, and coarse particles. PM emissions from road vehicles include the exhaust emissions (tailpipe) and non-exhaust emissions (wear and tear of vehicle parts and re-suspension dust). The major PM emitted from non-exhaust emissions is likely to be coarse particulate matter (PM2.5-10) while PM2.5 is the main particulate matter contributed from exhaust emissions. PM is a chemically complex and dynamic mixture of solid and liquid particles. Sources of PM include both natural and anthropogenic processes resulting in various morphologies and compositions. It can contain combinations of inorganic ions, elemental carbons, various trace elements, crustal compounds, organic compounds, and biological matter [1]. In urban areas, the composition of PM2.5 at roadside sites was dominated by the carbonaceous combustion component and the secondary ammonium nitrate/sulphate [2].

Black carbon (BC), representing the fraction of carbonaceous compounds, is the major constituent of PM2.5 mass concentrations. The fraction of BC in PM2.5 mass concentration in urban areas was approximately 38% [3]. In developing countries, BC characterization has become increasingly concern due to its effects on human health and climate. BC lifetimes has typically ranged from 6-10 days in the absence of precipitation and to be easily transported over long distances. BC is often emitted from incomplete combustion of fossil fuels and biomass burning. In urban environments, transportation has been identified as a significant contributor of BC emissions. Ambient BC concentrations were found in the range of 1.0-15.4 μg/m3 elsewhere [3–5]. BC has been reported to be an adequate indicator of diesel soot in urban areas. Due to the being particles with large specific surface area, BC could be an efficient absorber and a carrier of toxic substances, and can penetrate deeply into the human respiratory system [6]. Epidemiological studies have linked particles containing black carbon (BC) with adverse human health effects. Smith et al. [7] reported that, based on a concentration of 1 μg/m3, the percentage increase in all-cause mortality for PM2.5 was 0.58. The effects of sulphate were approximately twice those of PM2.5, while the effects of elemental carbon (EC, an indicator of black carbon mass) were about ten times greater.EC and BC have all been associated with negative cardiovascular health effects [8]. Long-term exposure to traffic-related air pollution, especially to diesel exhaust, has been associated with an increase in cardiopulmonary mortality [9–10] showed that cardiac admissions to hospitals for all ages increased by about 1.1% per 10 μg/m3 increase in black smoke, suggesting a significant role of diesel exhaust.

The increasing severity of road transportation has the potential to greatly increase pollutant emissions, which also have an influence on health, economy, and society. Nowadays, the routine automatic ambient air quality monitoring of fixed roadside stations in Bangkok mainly focuses on parameters of NOx, CO, O3, and PM10, while PM2.5 was only an addition in some monitoring stations. The measurements of BC, which are more health-damaging, are not included in routine monitoring programs. At present, BC concentrations in Thailand are only reported by researchers, thus, more information on traffic-related BC mass is required. The purpose of this study is to monitor and analyse the traffic-related BC concentrations and their relationships with major roadside pollutants in urban areas of Bangkok. Atmospheric dispersion of BC emitted from vehicles will be investigated using a mathematical model. The mitigations for air quality management, especially the black carbon aspect in urban areas, are expected if possible.

2 Material and methods

Bangkok is located at 13.45 latitude and 100.31 longitude and it is situated at elevation 12 meters above sea level. The climate of Bangkok is a tropical monsoon climate and is under the influence of southwest monsoon and northeast monsoon. It has three seasons as follows: rainy (wet season) or southwest monsoon season (mid-May to mid-October), winter (dry season) or northeast monsoon season (mid-October to mid-February), and summer or pre-monsoon season (mid-February to mid-May) [11]. The monitoring of black carbon (BC) in this study was done from November 28th, 2016 – January 4th, 2017 because this period was usually under the influence of the dry season.

2.1 Sampling sites

Samples were collected from automatic continuous air quality monitoring stations located in the Bangkok area. Due to resources and time limitations, only two stations (Bangna station and Thonburi station) were selected for this study period. These two air monitoring stations were managed by the Pollution Control Department (PCD) of Thailand and their locations as shown in Figure 1.

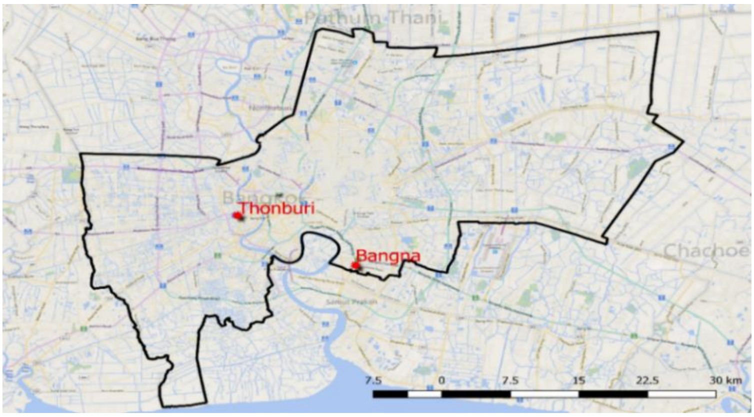

Fig. 1. Location of two monitoring stations in this study.

For the Bangna station, it was installed in the area of Thai Meteorological Department Bangna, Bangkok Thailand (13° 39′ 52′ N, 100° 36′ 35′ E). "Bangna" is also the name of the district of BMA with less density than Thonburi district (about 5,020 populations/km^2). This station is defined as a general station located at the south-southeast side of Sukhumvit Road and about 700 meters far from the Bangna Intersection and Bangna Expressway. However, Sukhumvit Road is one of the main roads connected to Samut Prakarn Province with high traffic density (especially diesel vehicles/trucks) and congestion during rush hours. This Sukhumvit road is surrounded by several commercial buildings and residential areas. Moreover, there is the sky train structure covering some parts of this road, especially near this monitoring station. In this study, BC samples were collected on the rooftop of this Bangna station, which was 150 meters away from the curbside of the Sukhumvit road (Figure 2a). The investigation of black carbon occurrence in this station was expected to be interesting.

For Thonburi station, "Thonburi" is the name of the southern district of Bangkok Metropolitan Administration (BMA), which is considered one of the high-density districts of BMA (13,487 populations/km^2). This Thonburi air quality monitoring station is located near the Metropolitan Electricity Authority (MEA), Thonburi Substation (13°43′30′ N, 100°29′9′ E) and about 100 meters from Bang Yi Ruea Junction. This station is defined as a roadside monitoring station located on the north side of Intharapitak road surrounded by several commercial buildings and residential areas. Intharapitak road is composed of six lanes with a total width of 21 meters, which is one of the main roads with high traffic density and congestion during rush hours. The structure of this Thonburi station was installed very close to the road area (5 meters away from the curb side) as shown in Figure 2b. The aethalometer was equipped on the rooftop of this station to collect black carbon (BC) samples with permission from PCD. Traffic in this area was postulated to play an important role in the air quality monitoring data of this station.

(a) (b)

Fig. 2. Maps of Thonburi station and Bangna station.

2.2 Samples collection and data analysis

Black carbon concentrations were measured by using Model AE-42 aethalometer (Magee Scientific, Berkeley, CA, USA). According to Hansen [12], seven wavelengths (UV at 370 nm, Blue at 470 nm, Green at 520 nm, Yellow at 590 nm, Red at 660 nm, IR-1 at 880 nm, and IR-2 at 950 nm) were set up. The sampling part of this aethalometer allowed only particles smaller than 2.5 µm in aerodynamic diameter to be collected on a quartz fiber tape. A sampling flow rate of 2 liters/minute and the 2 min data logging interval were designated.

Black carbon (BC) concentrations were measured during the dry season, covering weekdays (Monday to Friday) and weekends (Saturday, Sunday, and Holidays) as concluded in Table 1. At the Bangna station, the total days of BC data were 18 days, consisting of 12 days of weekdays, 2 days of Saturday, and 4 days of Sunday/Holiday. For Thonburi station, BC data were collected for 21 days (consisting of 13 weekdays, 3 days on a Saturday and 5 days on a Sunday/Holiday).

Particulate matter (PM2.5 and PM10), gaseous pollutants (CO, NO_2, O_3), and meteorological data (wind speed, wind direction, temperature, relative humidity, and precipitation) of these two air monitoring stations were supported by PCD.

Table 1. Sampling sites and number of BC data in this study

Sites	Total (Days)	Weekday		Weekend*	
		(Days)	(Hours)	(Days)	(Hours)
Bangna (Nov 28 – Dec 15, 2016)	18	12	211	6	134
Thonburi (Dec 15, 2016 – Jan 4, 2017)	21	13	278	8	191

Note : *Weekend = Saturday and Sunday/Holiday

2.3 Traffic count

Traffic volumes related to the monitoring stations were analysed by using digital video files of nearby CCTV cameras obtained from the Traffic and Transportation Department, Bangkok Metropolitan Administration. The number of vehicles passing through the camera was manually counted for at least twenty minutes in every hour, then hourly data were interpolated. Vehicles were categorized into eight different types, that is, passenger cars, pick-ups, vans, taxis, motorcycles, three-wheelers (or "Tuk Tuk"), buses, and trucks.

3 Results and Discussion

3.1 Black carbon (BC) and particulate matter (PM)

In the case of the Bangna station, the averages of PM10 and PM2.5 data obtained from the PCD (Pollution Control Department of Thailand) system during the same period of BC sampling were 58±25 and 46±18 μg/m^3, respectively. However, their maximum concentrations were observed as high as 164 and 118 μg/m^3, respectively. The average black carbon (BC) concentration of this station was 4.3±2.0 μg/m^3 while the median and the maximum were 3.8 and 14.2 μg/m^3, respectively.

For the Thonburi station, PM10 and PM2.5 were observed with averages of 57±25 and 44±19 μg/m^3, respectively, the maximum concentrations of which were 170 and 125 μg/m^3, respectively. The average BC concentrations from this station were 5.1±2.9 with a median and a maximum of 4.3 and 20.4 μg/m^3, respectively.

From the results, the averages of particulate matter (PM10 and PM2.5) observed from both stations were quite similar, while their black carbon (BC) concentrations showed a slightly higher range in the Thonburi station. This could be possibly due to the shorter distance between the equipment and the road (about 5 m) than the Bangna station (about 150 m.). However, the averages of BC concentrations from the Thonburi station in this study were quite lower than the average of 17.9±6.6 μg/m^3 reported in the previous study [13], which they monitored at another roadside monitoring station in the Bangkok area (Dindaeng station) during the dry season. Some other densely populated cities reported higher BC concentrations such as Istanbul in Turkey or London in the United Kingdom — which reported BC concentrations of 8.9±3.6 μg/m^3 [5] and 9.7±0.8 μg/m^3 [14], respectively.

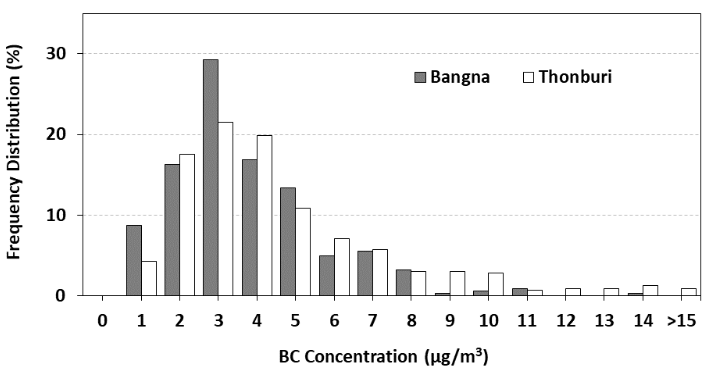

Fig. 3. Percentage occurrence of BC mass concentrations at two sampling stations.

In comparison between these two stations, Thonburi station showed that their hourly BC data higher than 10 μg/m^3 were recorded during the sampling period more frequently (4.5%) than the Bangna stations (1.2%). The frequency distribution of hourly BC concentrations in Figure 3 supported that the majority of hourly BC concentration data from both stations were still in the range of less than 10 μg/m^3. Other urban cities that also reported their BC concentrations in a similar range, e.g., Chiang Mai province in northern Thailand observed BC data less than 3.3 μg/m^3, and biomass-burning (both forest fire and agricultural burning) was mentioned as the cause [15]. Shanghai in China reported that 91% of their BC data were less than 6 µg/m^3 [16]. The BC data in the range of 1 – 5 µg/m^3 was recorded with a frequency of 62% in Ostrava, Czech Republic [17]. Differently, Istanbul in Turkey showed a little higher BC concentration, with their frequency of BC data higher than 10 µg/m^3 was as high as 40% of total data [3].

3.2 Diurnal variation of BC concentrations

This study was to investigate black carbon occurrence in the urban areas of Bangkok Metropolitan. Vehicles emission was expected to be an important source of black carbon in this urban area. Any activities of biomass burning and grilled street foods were observed very little in the surrounding area of these two stations, however, these effects were not verified in this study. Traffic characteristics should be related to BC accumulation in the surrounding ambient air. Therefore, sampling periods were assigned to cover both weekdays–weekends pattern and daytime–nighttime pattern. Weekdays mean Monday to Friday, while weekends mean Saturday to Sunday. Daytime was specified as 6:00 – 18:00 and nighttime was 18.00 – 06.00. Statistically, hourly BC concentrations obtained from these two stations were calculated for discussion both weekdays–weekends and daytime–nighttime patterns as presented in Table 2. During weekdays, the averages of daytime data from the Bangna station (3.7 µg/m^3) and Thonburi station (5.2 µg/m^3), were less than those of nighttime data (4.8 and 5.6 µg/m^3, respectively). Similarly, the averages of daytime data during weekends (3.9 and 4.4 µg/m^3, respectively) were less than those of nighttime data (4.5 and 5.0 µg/m^3, respectively) as well.

Table 2. Statistics of hourly BC concentrations in this study

Sites	Parameter	Weekday		Weekend	
		Daytime	Nighttime	Daytime	Nighttime
Bangna	range	1.2 – 12	2.1 – 14	1.4 – 11	2.7 – 8.8
(µg/m^3)	average ± sd	3.7 ± 2.1	4.8 ± 2.0	3.9 ± 1.9	4.5 ± 1.6
	median	3.1	4.6	3.6	4.8
Thonburi	range	1.7 – 15	1.1 – 20	1.2 – 9.7	1.9 – 18
(µg/m^3)	average ± sd	5.2 ± 3.1	5.6 ± 3.5	4.4 ± 1.6	5.0 ± 2.7
	median	4.4	4.5	4.1	4.3

For the Thonburi station, averages of daytime (5.2 µg/m^3) and nighttime (5.6 µg/m^3) during weekdays appeared to be higher than their weekends (4.4 and 5.0 µg/m^3, respectively). This could be due to less traffic congestion during weekends on this Intharapitak road (Thonburi station). For the Bangna station, there seemed not to be a substantial difference between weekdays and weekends. This Sukhumvit road is a main road connecting to Sumutprakarn Province, where transportation for industrial and commercial purposes with heavy-duty vehicles are found. The density of vehicles increased particularly on weekends due to these heavy-duty vehicles being allowed to access the inner part of the Bangkok Metropolitan area. Hence, the diurnal variation of BC concentrations on weekends at this station was a little higher than those on weekdays.

3.3 Correlation between black carbon (BC) and PM2.5

Due to black carbon (BC) representing a significant fraction of PM2.5 concentrations in the urban atmosphere, Figure 4 shows the hourly variation of BC and PM2.5 concentrations at the Bangna station. The diurnal variation of BC and PM2.5 was quite consistent similarly to those of Thonburi station (Figure 5). However, the hourly concentrations of BC and PM2.5

(at this Bangna Station) showed a significant morning peak at approximately 7:00 to 8:00. Then, BC and PM2.5 decreased toward midday and increased in the evening. The second peaks of BC and PM2.5 were observed at around 21:00 (a little earlier than Thonburi station). The measurement results showed these two peaks of BC concentrations happening in the morning and the late evening, similar to other studies [3, 18–20]. According to the explanations of the previous studies, this could be postulated that BC concentrations in this study should be correlated to traffic emissions and the formation of boundary layer height.

Figure 5 illustrates the hourly variation of BC and PM2.5 concentrations observed from the Thonburi station. The diurnal variation of these BC and PM2.5 concentrations was consistent. The hourly concentrations of BC and PM2.5 showed a significant morning peak at approximately 5:00 to 6:00, which further decreased toward midday and increased again during the evening. Both pollutants showed a second peak at around 21:00 to 23:00. This variation suggested that traffic congestion, particularly during morning (5:00 to 7:00) and evening (16:00 to 17:00) rush hours, led to higher concentrations of pollutants.

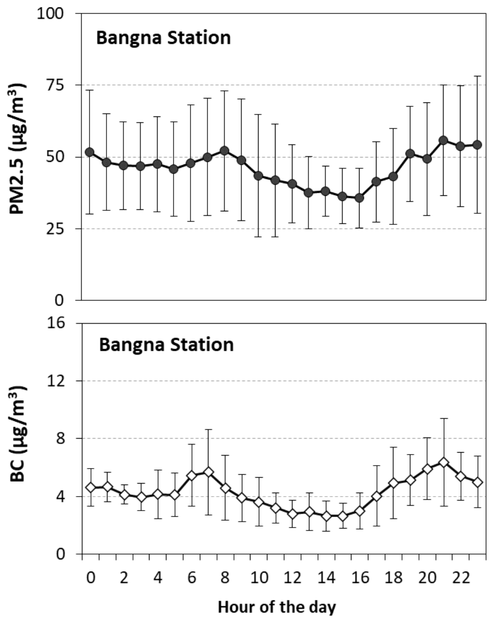

Figure 4. Hourly variation of BC and PM2.5 concentrations of Bangna station.

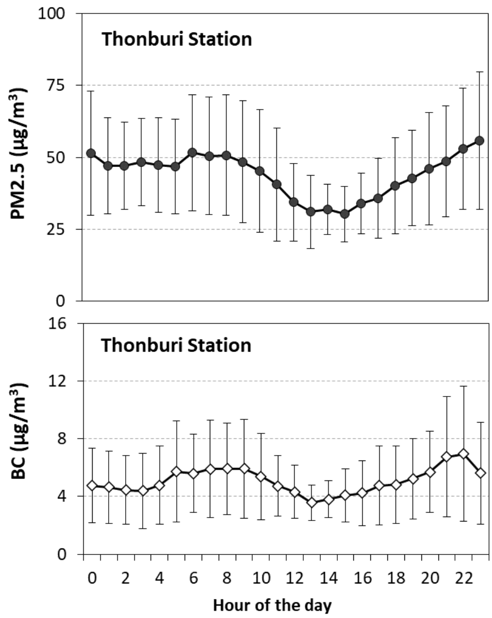

Figure 5. Hourly variation of BC and PM2.5 concentrations of Thonburi station.

3.4 Traffic characteristics

Due to the assumption that BC concentrations in urban areas were somehow influenced by traffic characteristics, traffic volumes on the roads near the monitoring station during the sampling period were also observed. At the Bangna station, total vehicle volumes on Sukhumvit road during the sampling period were counted in the range of 189 – 11,424 vehicles/hour, of which the average was 3,549 vehicles/hour. The average vehicle volume on weekdays and weekends was 3,577 and 3,625 vehicles/hour, respectively (table 3). Motorcycle (29 – 30%) was the highest composition of this Sukhumvit road similar to the Intharapitak road. The others were private cars (26 – 27%), pickups (21 – 22%) and taxis (14 – 15%). For vans, buses, and trucks, each held its share of around 2 – 4%, and tuk-tuks held the smallest share of below 1%. The dominant shares of motorcycles, private cars, pickups, and taxis were observed similarly both during weekdays and weekends.

At the Thonburi station, the total vehicle volume on Intharapitak road during the sampling period was counted in the range of 648 – 6,900 vehicles/hour. The averages during weekdays and weekend were 3,993 and 3,576 vehicles/hour, respectively (Table 3). The fleet composition was dominated by motorcycles (37 – 38%), private cars (27%), taxis (18-19%), and pickups (11-12%), while the others held a share of 1 – 4%. The smallest composition of this Intharapitak road belonged to the truck fleet (less than 1%). The higher shares of motorcycles, private cars, taxis, and pickups were observed similarly both during weekdays and weekends. However, the compositions of private cars, taxis, and Tuk–Tuks tended to increase during weekends.

Table 3. Percentage of traffic fleets composition (%).

Vehicle type	Intharapitak road		Sukhumvit road	
	Weekdays	Weekends	Weekdays	Weekends
Private car	26.6 ± 1.0	27.2 ± 0.8	26.5 ± 0.7	26.3 ± 0.3
Pickup	12.0 ± 0.3	11.4 ± 1.1	20.6 ± 1.2	21.8 ± 1.0
Van	1.0 ± 0.1	0.7 ± 0.0	3.0 ± 0.2	3.1 ± 0.2
Taxi	17.5 ± 0.5	18.7 ± 3.0	15.2 ± 0.7	14.3 ± 0.4
Motorcycle	37.5 ± 1.4	36.7 ± 2.5	28.9 ± 0.7	28.5 ± 0.3
Tuk-Tuk	3.1 ± 0.2	3.7 ± 0.0	0.2 ± 0.1	0.2 ± 0.0
Bus	1.7 ± 0.1	1.4 ± 0.0	3.5 ± 0.1	3.7 ± 0.2
Truck	0.6 ± 0.1	0.5 ± 0.2	2.0 ± 0.2	2.1 ± 0.4
Average (vehicles/hour)	3,993 ± 108	3,576 ± 369	3,577 ± 1,013	3,625 ± 208

4 Conclusions

Hourly BC concentrations in this study were measured with a single-wavelength Aethalometer at two air monitoring stations, one roadside station (Thonburi station), and a general station (Bangna station) in Bangkok during the dry season of the year 2016-2017. The results showed the level of BC concentrations from the roadside station was a little higher than that from the general station, possibly due to the distance from the main roads. Two peaks of BC concentrations in this study were more likely due to rush hour traffic concurrently with meteorological conditions. The main emission sources of BC concentrations should be emitted from local vehicular emissions due to BC peak concentrations being correlated to traffic rush hours. Heavy-duty diesel vehicles should be an important fleet affecting BC concentrations, especially during nighttime and weekends. However, analytical results imply that BC concentrations in urban Bangkok were not only released from fossil fuel emissions, but also emitted from biomass burning emissions. From the dataset elsewhere [21], BC concentrations showed a significantly positive correlation with air pollutions, particularly, PM10, PM2.5, CO, and NO_2. This finding indicated that the main sources of these pollutants in study areas were emitted from vehicle emissions, residential combustion, and industrial combustion. In addition, a recent study of black carbon across urban Europe [22] showed a decrease in equivalent BC emissions from traffic over the past decade, but those from residential and commercial combustion were almost the same. Recently, the PM2.5 crisis in the Bangkok area has been discussed, and its causes are not only from traffic, but also from biomass burning (both local and regional areas). Further study and monitoring of PM2.5 with black carbon (or elemental carbon) should be strongly recommended.

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References

1. K. Yoo, J. Ji, A. Aufdenkampe, J. Klaminder, J. Geophys. Res. **116**, G01014 (2011)
2. R.M. Harrison, A.M. Jones, R.G. Lawrence, Atmos. Environ. **38**, 4531–38 (2004)
3. H. Ozdemir, L. Pozzoli, T. Kindap, G. Demir, B. Mertoglu, N. Mihalopoulos, C. Theodosi, M. Kanakidou , U. Ime, A. Unal, Sci. Total. Environ. **473–474**, 451–8 (2014)
4. Y.H. Cheng, B.S. Shiu, M.H. Lin, J.W. Yan, Environ. Sci. Pollut. Res. **20**, 1537–45 (2013)
5. J. Feng, M. Zhong, B. Xu, Y. Du, M. Wua, H. Wang, C. Chen, Atmos. Res. **147–148**, 1–9 (2014)
6. G. Pavese, M. Calvello, F. Esposito, Aerosol. Air. Qual. Res. **12**, 1146–56 (2012)
7. K.R. Smith, M. Jerrett, H.R. Anderson, R.T. Burnett, V. Stone, R. Derwent, R.W. Atkinson, A. Cohen, S.B. Shonkoff, D. Krewski, C.A. Pope 3rd, M.J. Thun, G. Thurston, Lancet. **374**, 2091–103 (2009)
8. K.I. Jansen, T.V. Larson, J.Q. Koenig, T.F. Mar, C. Fields, J. Stewart, L. Morton, Environ. Health. Perspect. **113**, 1741–46 (2005)
9. R.D. Brook, S. Rajagopalan, C.A. Pope 3rd, et al., Circulation. **121**, 2331–78 (2010)
10. A. Tertre, P. Quenel, D. Eilstein, et al., Arch. Environ. Health. **57**, 311–9 (2002)
11. Thai Meteorological Department (TMD), Weather of Bangkok (2017)
12. A.D.A. Hansen, *The aethalometer*™ Magee Scientific Company Berkeley, California, USA. Available from: http://mageesci.com/support/downloads/Aethalometer_book_2005.07.03.pdf. (2005)
13. N.T.Q. Hung, S.B. Lee, N.T. Hang, J. Kongpran, N.T. Kim Oanh, S.G. Shim, G.N. Bae, Atmos. Environ. **92**, 231–9 (2014)
14. V. Singh, K. Ravindra, L. Sahu, R. Sokhi, Atmos. Environ. **178**, 148–57 (2018)
15. S.K. Pani, S. Wang, N. Lin, S. Chantara, C. Lee, D. Thepnuan, Environ. Pollut. **259**, 112871 (2020)
16. S. Zha, T. Cheng, J. Tao, et al., Atmos. Res. **135-136**, 159–71 (2014)
17. M. Kucbel, A. Corsaro, B. Svedova, H. Raclavska, K. Raclavsky, D. Juchelkova, J. Environ. Manage. **203**, 1178–89 (2017)
18. L. Shen, L. Li, S. Lu, X. Zhang, J. Liu, J. An, G. Zhang, B. Wu, F. Wang, Particuology **20**, 10–15 (2015)
19. X. Zhang, R. Rao, Y. Huang, M. Mao, M.J. Berg, W. Sun, J. Quant. Spectrosc. Radiat. Transfer. **150**, 3–11 (2015)
20. A.C. Targino, P. Krecl, Aerosol. Air. Qual. Res. **16**, 125–37 (2016)
21. P. Phanukarn, Analysis of Black Carbon and Traffic-related Air Pollutants in Bangkok Area [PhD Dissertation in Environmental Technology]. Bangkok: Department of Sanitary Engineering, Faculty of Public Health, Mahidol University (2019)
22. M. Savadkoohi, M. Pandolfi, C. Reche, J.V. Niemi, D. Mooibroek, et al., Environ. Int. **178**, https://doi.org/10.1016/j.envint.2023.108081 (2023)