P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol. 28 No.3 July – September 2023
Page: [178-197]
Original research article

Estimating the Relationship between Particulate Matter and MODIS AOT in the Bangkok Metropolitan Region, Thailand

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Received 10 February 2023; Received in revised form 18 August 2023
Accepted 15 September 2023; Available online 26 September 2023

ABSTRACT

Bangkok (BKK) and Pathumthani (PT), Thailand, have faced air pollution problems every year. The main factors contributing to air pollution emissions in BKK and PT are vehicles, industries, open burning, and agricultural residual burning. Air quality monitoring stations in BKK and PT are limited, and some regions have no stations, so this research would like to solve that problem. The research effort is to estimate the dispersion of coarse and fine particles (PM_{10} and $PM_{2.5}$) in the atmosphere in BKK and PT from January 2018 to May 2020. PM_{10} and $PM_{2.5}$ levels were collected from 13 stations that were investigated before the COVID-2019 Lockdown. The results of this study show the average PM_{10} concentrations in the range 19.36-55.47 μg/m^{-3}, while the average $PM_{2.5}$ concentrations are found in the range 6.33-22.80 μg/m^{-3}. The correlation of PM_{10} and $PM_{2.5}$ at ground-based stations and PM_{10} and $PM_{2.5}$ from the aerosol optical thickness (AOT) retrieved by the Moderate Resolution Imaging Spectroradiometer (MODIS). Results reveal positive correlations with correlation coefficients (R2) equal to 0.398 and 0.560 for PM_{10} and $PM_{2.5}$, respectively. The Pearson correlation coefficient was used to explore the influence of meteorological factors on PM_{10} and $PM_{2.5}$ concentrations. The correlation results presented positive relationship, major factors were pressure, temperature, RH and wind speed. Multiple regression analysis (MRA) stepwise shows that meteorological factors affected PM_{10} concentrations at 68.10% with high relative values for pressure, RH, visibility, and AOT, and $PM_{2.5}$ concentrations at 50.20% with high relative values for wind speed and could cover, respectively ($p < 0.01$).

Keywords: Air Quality; AOT; Bangkok; Coarse particle (PM_{10}); Fine particle ($PM_{2.5}$); MODIS

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doi: 10.14456/scitechasia.2023.54

1. Introduction

Bangkok (BKK) is the capital of Thailand, and Pathumthani (PT) Province is a suburb of Bangkok. These two sites have been facing an extremely high distribution of haze pollutants. The major haze pollutant in urban and rural areas in Thailand is particulate matter (PM). Currently, airborne fine particulates ($PM_{2.5}$ or particulate matter (PM) with a diameter less than 2.5 μm) have gained increasing attention for their potential toxicities and roles in visibility and health [1]. In all regions of Thailand, $PM_{2.5}$ is present in large amount in the dry season. This is caused by seasonal variations, the burning of agricultural residues, or forest fires occurring during the dry season [2-6]. The effect of PM_{10} during haze episodes (2007-2013) in Chiang Mai showed that both male and female children aged 0-14 years old were the most exposed to respiratory diseases [2]. The research conducted by Chomanee et al. [6] stated that the concentration of PM due to biomass burning in the southern region of Thailand in 2017 was adversely toxic compared to 2015, 0.89±0.17 ng/m^3 and 3.34±2.54 ng/m^3, respectively. In Bangkok, the possible impacts of air pollution have been determined by multi researchers, university and governments; for example, the admission of cardiovascular and respiratory diseases increased NO_2, SO_2, O_3 and $PM_{2.5}$, emitted (reach to 10 μg/m^3), particularly for the group aged above 65 years old, which accounted for cardiovascular in O_3 (0.34 to 0.63 μg/m^3), NO_2 (0.87 to 1.69 μg/m^3), SO_2 (6.16 to 10.74 μg/m^3), and $PM_{2.5}$ (0.68 to 1.41 μg/m^3) while respiratory was (0.18-1.21μg/m^3), (0.98 to 1.85 μg/m^3), (2.22 to 6.80 μg/m^3), and $PM_{2.5}$ (0.79 to 1.57 μg/m^3), respectively [7]. A study by Fold NR et al. [8] showed that there are 4,240 non-accidental, 1,317 cardiopulmonary, and 370 lung cancer mortalities resulting from the haze pollution of fine PM every year. Air quality and its sources in BKK and BMR have been the subject of several studies. In 2018, the concentration of $PM_{2.5}$ was gradually exceeding the limit concentration as recommended by the WHO by 2-5 times [9]. Kanchanasuta et al. [10] reported that the highest loading concentrations of $PM_{2.5}$ and PM_{10} occurred at 9:00 a.m., while the lowest was at 3:00 p.m. A wind resulted in a rise in the PM_{10} and $PM_{2.5}/PM_{10}$ ratio. Vehicular and biomass burning are the main sources of elevated ambient air pollution in Bangkok [9-14]. For instance, biomass burning during the dry season was attributed to a surge in the amount of $PM_{2.5}$ compared to other sources [11]. Narita et al. [9] revealed that the important sources of increased $PM_{2.5}$ concentrations were biomass burning and transportation (41% and 23%, respectively). The concentration of $PM_{2.5}$ accounted for 77.0±21.2 μg/m^3 compared to organic carbon (8.03±4.02 μg/m^3) and elemental carbon (2.62±1.49 μg/m^3), and it was mainly sourced from vehicular exhaust (43.7%), biomass burning (24.0%), sea salt aerosol (10.5%), power plants (6.48%), and industrial emissions (4.46%) [13]. Recently, the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Terra satellite was applied for assessment and distribution of air pollution problems, particularly particulate matter. The MODIS product has been demonstrated to widely report particles on both local and global scale. Jamil et al. [15] concluded that MODIS is an effective tool to monitor the PM air quality in any place where there is insufficient ground measurement. Another study by Zheng et al. [16] in China illustrated that this model enabled characterization of the temporal and spatial variation of PM pollution and identified its sources with an error less than 50%. Using satellite data resulted in successfully improving air pollution control by haze emission in the northern regions of Thailand [5]. Therefore, it is significant to conduct the study using satellite-retrieved Aerosol Optical Thickness (AOT) data to estimate ground-level PM_{10} and $PM_{2.5}$ concentrations.

2. Materials and Methods

2.1 Study area

This work focused on two sites to estimate PM levels 1) The Bangkok location has a high density of transportation vehicles and residences [12]. 2) Pathum Thani Province is a suburban region near Bangkok. It also has a high number of vehicles that have an effect on PM_{10} and $PM_{2.5}$ as well.

2.2 Ground-level PM_{10} and $PM_{2.5}$ monitoring data

The ground-level PM_{10} and $PM_{2.5}$ concentrations of this work were obtained by the Pollution Control Department (PCD). This research took average monthly ground-level PM_{10} and $PM_{2.5}$ concentrations from the website. The data from all 13 stations are referred to in this work, as shown in Fig. 1 and Table 1.

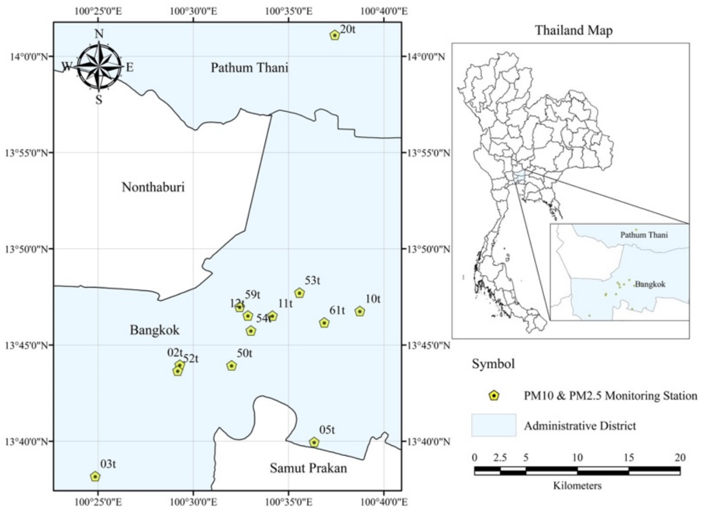


Fig. 1. The location of the particulate matter and meteorological stations in this study.

Table 1. The location of the air quality stations in this study.

NO.	Station Code	Station Name	District	X	Y
1	02t	Bansondejchaopraya Rajabhat University, Bangkok	Nonthaburi	660916	1518694
2	03t	Thanon Kanchanaphisek, Bangkok	Bangkhunteian	652978	1507973
3	05t	Thai Meteorological Department Bangna, Bangkok	Bangna	673673	1511376
4	10t	National Housing Authority Khlongchan, Bangkok	Khlongchan	677905	1523954
5	11t	National Housing Authority Huaykwang,Bangkok	Dindang	669642	1523453
6	12t	Nonsi Witthaya School, Bangkok	Yannawa	667326	1523453
7	20t	Bangkok University, Rangsit Campus	Pathumtani	675358	1550390
8	50t	Chulalongkorn Hospital Bangkok	Pathumwan	665811	1518665
9	52t	EGAT, Thonburi	Thonburi	660721	1518126
10	53t	Chokchai Police Satation, Bangkok	Wangthonglang	672189	1525672
11	54t	National Housing Authority Dindang, Bangkok	Dindang	667613	1522012
12	59t	The Government Public Relations Department,Bangkok	Phayathai	666536	1524277
13	61t	Bodincha Sing Singhaseni School, Bangkok	Wangthonglang	674551	1522835

2.3 Meteorological Parameter

The weather conditions in both areas were obtained from a relevant government official [17]. Temperature (°C), relative humidity (RH), wind speed (WS) and wind direction, rainfall, and cold cover are all included in the 2018-2020 meteorological forecast (https://www.tmd.go.th/) [17]. All parameters are associated with PM distribution.

2.4 Data Integration

AOT data is collected from the MODIS instrument on board the Terra and Aqua satellites, with a spatial resolution of 10 km; NASA research teams retrieved AOT with a resolution of 3 km as part of collection 6. Because of data unavailability and cloudy weather limitations on many days during the study period, the representative of the weekly MODIS-Aerosol product MOD04 dataset was randomly selected during our study period (2018 to 2020). Subsequently, representative average monthly AOT and PM_{10} and $PM_{2.5}$ data set were produced. In 2018, the data was 20 days, followed by 20 days in 2019, and 11 days in 2020. AOT data from the MODIS sensor was used in the study to observe the trend and pattern of PM_{10} and $PM_{2.5}$ over BKK and PT. The MODIS sensor on board EOS-Terra and Aqua satellites has 36 spectral channels and is suitable for both temporal and spatial resolution. Both Terra and Aqua satellites daily cross Thailand between 10.30 and 13.30 local solar time. The AOT dataset retrieved for cloud-free pixels is available in the 550 nm band, which is generally used for climatological and air quality studies. The meteorological values were used at the nearest ground station. Many studies have reported several models of retrieving PMs at ground level from AOT measurements, and it seems each model is suited only for specific sites [5]. For this work, Eqs. (2.1)-(2.2) were calculated to estimate PM_{10} and $PM_{2.5}$ concentrations [18].

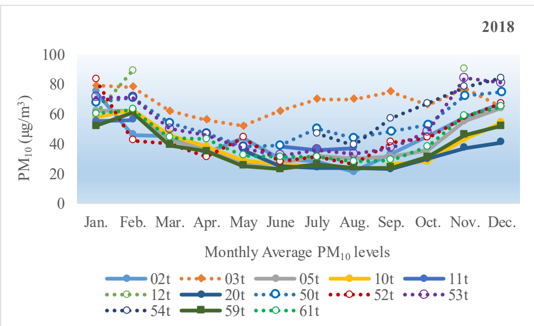
$$PM_{10} = 130.304 - (79.574 \times AOT) - (152.794 \times AOT^2) + (250.036 \times AOT^3), \tag{2.1}$$

$$PM_{2.5} = 63.66 \times AOT + 26.65. \tag{2.2}$$

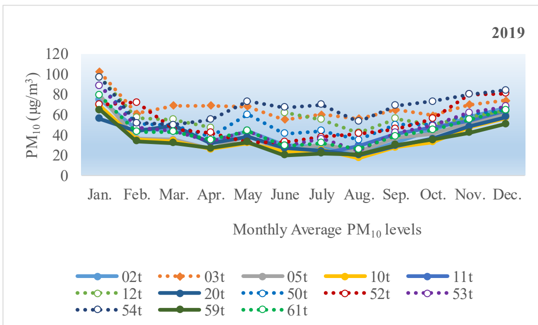
3. Results and Discussion

3.1 Ground-level PM_{10}, $PM_{2.5}$ monitoring data and AOT

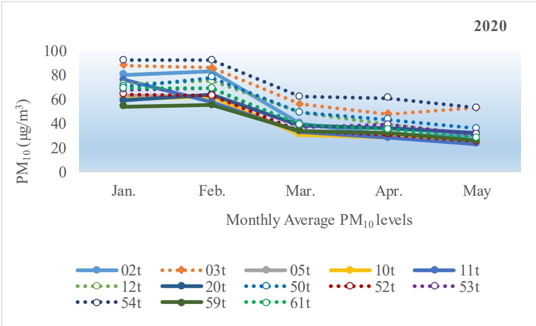
Coarse and fine particle measurements were conducted at 13 stations in Bangkok and Pathum Thani Province, which are BKK and PT from 2018 to 2020. Each monitoring station's average concentrations and PM levels were determined. Figs. 2(a)-(f) depict a temporal and spatial distribution of average PM_{10} and $PM_{2.5}$ concentrations. Estimation of PM_{10} and $PM_{2.5}$ concentrations at ground-level station monitoring was separated into two seasons of the year. The calculation of PM_{10} and $PM_{2.5}$ concentrations in the dry season refers to November until April and May to October for the wet season. The wet season in Thailand is associated with the summer monsoon, whilst the dry season is influenced by the winter monsoon. The temporal distribution of PM_{10} and $PM_{2.5}$ concentrations demonstrated that concentrations were higher in the dry season than in the wet season. However, it appeared that the patterns in the dry season were higher than the patterns in the wet season for all stations in every year, as shown in Fig. 2. The total concentration showed the maximum and minimum values of PM_{10} were 1,951 and 697 μg/m^3 at 03t station and 11t station, respectively. In Fig. 2(a), the results of this study show the average PM_{10} concentrations in the range 19.36-55.47 μg/m^{-3}, while the average $PM_{2.5}$ concentrations are found in the range 6.33-22.80 μg/m^{-3}. In 2018, monthly average PM_{10} concentrations were high at all monitoring sites in November (63.08 μg/m^3), December (65.00 μg/m^3), January (65.73 μg/m^3), and February (63.82 μg/m^3). The highest concentration of PM_{10} was reported at the 12t station (90 μg/m^3). In 2019, expect a similar trend. Monthly average PM_{10} concentrations were high at all monitoring sites from November to February, but low in August (Fig. 2(b)). The station which received the lowest value was 10t. We observed from January to May of 2020. In January, the 54t station has the highest level of pollution. This year, severe pollution was experienced in February and March (Fig. 2(c)). The result of this study shows that the air pollution in the dry is much worse than in wet season. According to the monthly series study below, the temporal variation of PM_{10} concentrations is related to their fluctuating emissions and seasonal weather. This study is similar to previous studies [9, 19, 20]. For $PM_{2.5}$, the maximum and minimum values were 821 and 228 μg/m^3 at 50t station and 12t station, respectively. In 2018, average monthly $PM_{2.5}$ concentrations from 02t and 12t were not reported data, whereas monthly average $PM_{2.5}$ concentrations from 03t, 10t, 11t, 20t, and 54t are limited. We calculated data and found high concentrations in November, December, and February. The highest reported value was 52t (55 μg/m^3) (Fig. 2(d)). In 2019, the months of November, December, and January had high $PM_{2.5}$ concentrations. In January, the maximum measurement of $PM_{2.5}$ is 62.00 μg/m^3 (03t) (Fig. 2(e)). In August, the lowest value is 9.00 μg/m^3 (10t). From January through May of 2020, we observed. The 54t station has the highest $PM_{2.5}$ level (92 μg/m^3) in January (Fig. 2(f)). PM_{10} and $PM_{2.5}$ concentrations affected BKK air quality main caused by combustion emission sources. Additionally, the dry average concentration was slightly higher when compared to the wet. The dry season was strong with PM_{10} and $PM_{2.5}$ levels in December and January at all stations. Fig. 2, presents the mass concentrations of PM_{10} and $PM_{2.5}$. The graph was created based on 13 stations. Fig. 2 shows a clear difference between the levels of PM_{10} and $PM_{2.5}$ in the dry season (November-April) and during the rainy season (May-October). The high amounts of PM_{10} and $PM_{2.5}$ during the dry season may be caused by the increase in traffic volume [10] and transportation. Because of the traffic congestion and the diesel fuel combustion, PM emissions are generated [21]. During the dry season in Thailand, conditions such as biomass burning and a lack of rain can have a considerable impact on the production of excessive particle matter. Pearson correlation was used to investigate the correlations between PM_{10} and $PM_{2.5}$ mass concentrations, and the results revealed that the coefficients of determination (0.72) were quite high, as shown in Table 2.



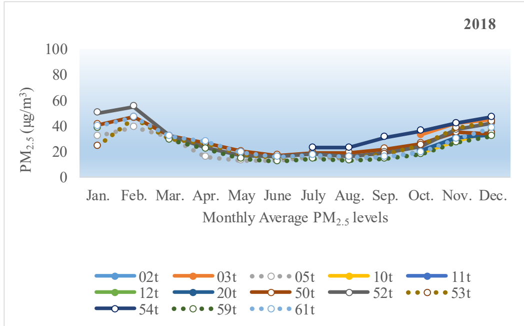
(a) PM_{10} (2018)



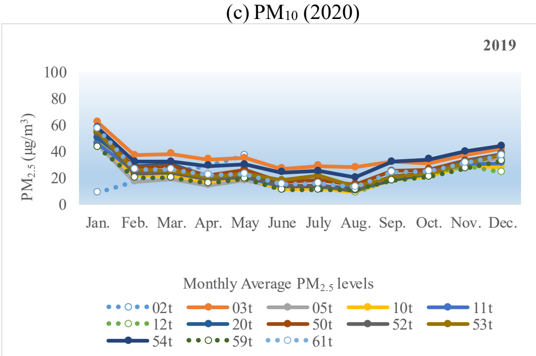
(b) PM_{10} (2019)



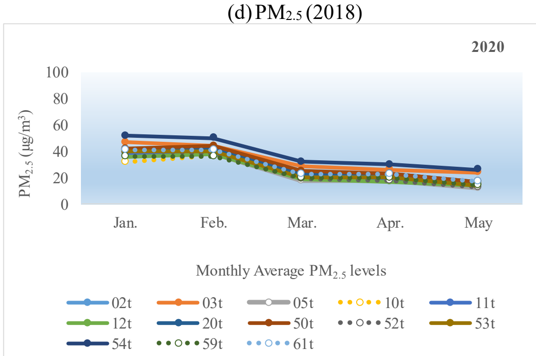
(c) PM_{10} (2020)



(d) $PM_{2.5}$ (2018)



(e) $PM_{2.5}$ (2019)



(f) $PM_{2.5}$ (2020)

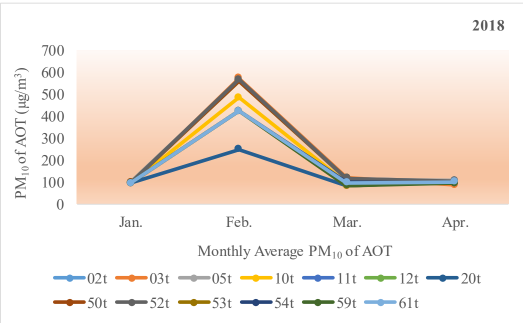
Fig. 2. The monthly average concentration of PM_{10} and $PM_{2.5}$ in BKK and PT from 2018 to 2020.

Table 2. The correlation coefficient for PM_{10}, $PM_{2.5}$ concentrations and AOT value at 13 stations, respectively.

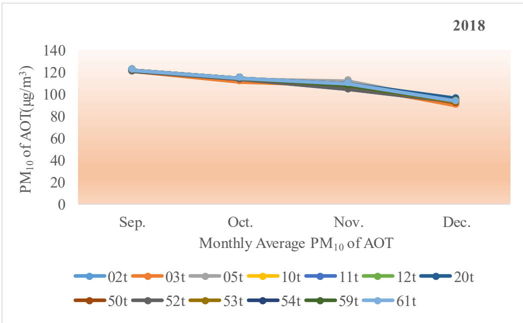
Parameter	Mean	PM_{10}	$PM_{2.5}$	PM_{10} AOT	$PM_{2.5}$ AOT
PM_{10}	35.57	1	0.72**	0.39**	0.56**
$PM_{2.5}$	16.89	0.72**	1	0.33**	0.55**
AOT	75.99	0.39**	0.33**	1	0.79**
$PM_{2.5}$ AOT	33.75	0.56**	0.55**	0.79**	1

Note: *$p < 0.05$, **$p < 0.01$

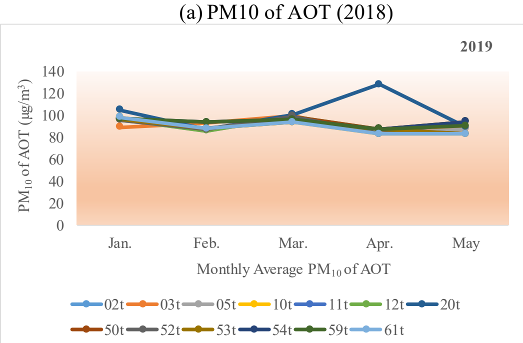
Another reason for $PM_{2.5}$ emission sources is that $PM_{2.5}$ mass could be attributed to high biogenic emissions observed during this season [9, 10, 19, 22-27]. The ratio of $PM_{2.5}/PM_{10}$ value of each station varied in range 0.18-0.79 which was determined by the average concentration of $PM_{2.5}$ divided by PM_{10}, which indicated that overall Bangkok presented more fine particulate matter than coarse particulate matter. The highest $PM_{2.5}/PM_{10}$ ratio was 0.79 observed at the 20t monitoring station, which is at a suburban background site and, mainly in traffic emission and close to the highway and the Don Mueang airport, whereas $PM_{2.5}/PM_{10}$ ratio was the lowest at 11t monitoring station (0.18), an urban background site. $PM_{2.5}/PM_{10}$ ratio showed a different proportion between the winter and summer seasons. The highest value of the $PM_{2.5}/PM_{10}$ ratio in winter was also observed in all monitoring stations. This showed a similar trend to the research report from Kanchanasuta et al. [10], where the ratio of $PM_{2.5}/PM_{10}$ was 0.63 and displayed more fine PMs than coarse fractions. Fuel combustion is observed at high levels in BKK and PT; this could be a suitable factor for consideration of increasing fine particle in study areas. Figs. 3(a)-3(e) depict AOT PM_{10} values, with the findings revealing the monthly average of all study locations. In 2018, Fig. 3(a) shows the results from January to April, whereas Fig. 3(b) depicts the results from September to October. There is no data from May to August. The information provided by MODIS may be limited. The results show that the average concentration is highest in February (479.30) and lowest in December (93.19). In February, the maximum measurement of AOT PM_{10} is 573.48 μg/m^3 (03t). In 2019, the monthly average AOT PM_{10} levels were high from October through January. In October, the maximum level was anticipated to be 110.61 μg/m^3 at the stations 10t, 11t, 53t, 54t, 59t, and 61t. The greatest AOT PM_{10} measurement in November is 103.31 μg/m^3 (20t), 103.18 μg/m^3 (53t) in December, and 104.33 μg/m^3 (12t) in January (Figs. 3(c)-(d)). The monthly average AOT $PM_{2.5}$ values in 2018 were high from December to February. The monthly averages were 50.01, 62.92, and 96.02 μg/m^3. In February, the maximum AOT $PM_{2.5}$ level was observed to be 03t (105.38 μg/m^3). The lowest level (32.38 μg/m^3) was reported in September (Figs. 3(f)-(g)). The highest level of AOT $PM_{2.5}$ in 2019 was reported in February, with a maximum level of 69.21 μg/m^3. The lowest level (46.58 μg/m^3) was reported in September (Figs. 3(h)-(i)). We calculated from January to May in 2020, and the expected findings revealed that April has the highest average concentrations compared to other months (Fig. 3(j)). In April, the highest level of AOT $PM_{2.5}$ was registered in 03t (74.06 μg/m^3). The lowest level (54.66 μg/m^3) was reported in May (Figs. 3(h)-(i)). Fig. 3 shows time series plots that exhibit missing values in several stations. We justified the line graph in two figures for the years 2018-2019. Because the data from each site is so varied, justifying the threshold is difficult. In this investigation, the monthly average concentrations are extremely dangerous for some sites, and seasonal variation impacts the PMs concentrations. PM_{10} and $PM_{2.5}$ levels must be kept under control and mitigated during the dry season.



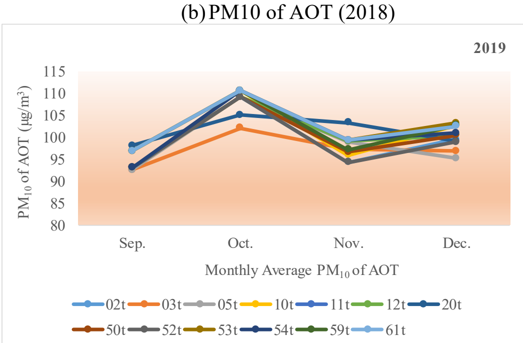
(a) PM10 of AOT (2018)



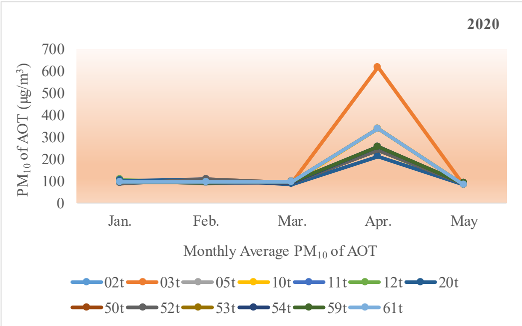
(b) PM10 of AOT (2018)



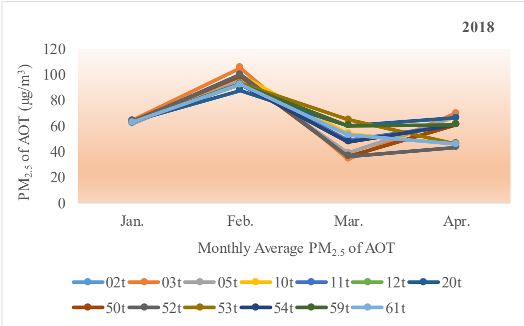
(c) PM10 of AOT(2019)



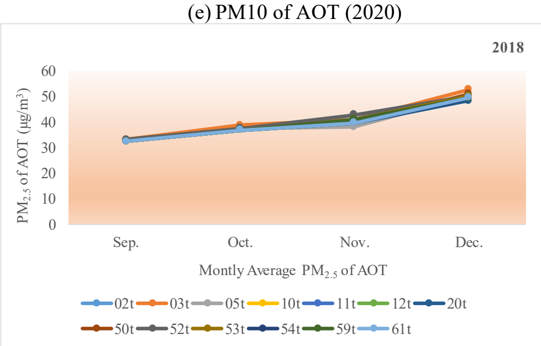
(d) PM10 of AOT (2019)



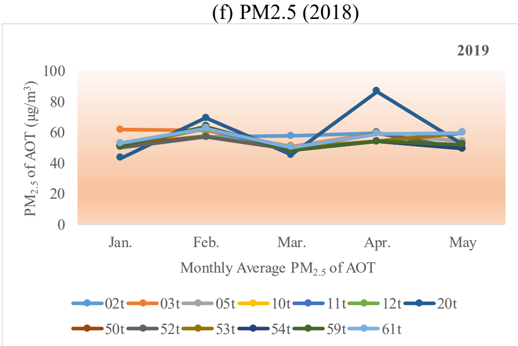
(e) PM10 of AOT (2020)



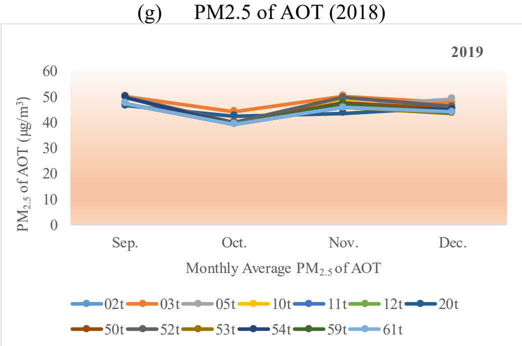
(f) PM2.5 (2018)



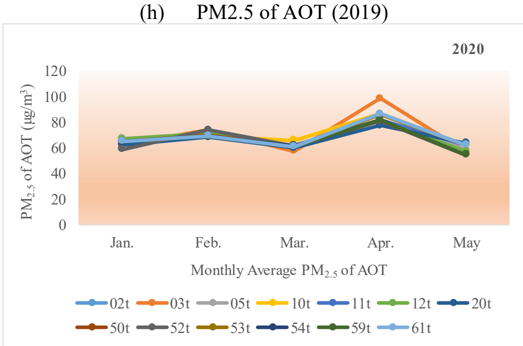
(g) PM2.5 of AOT (2018)



(h) PM2.5 of AOT (2019)



(i) PM2.5 of AOT(2019)

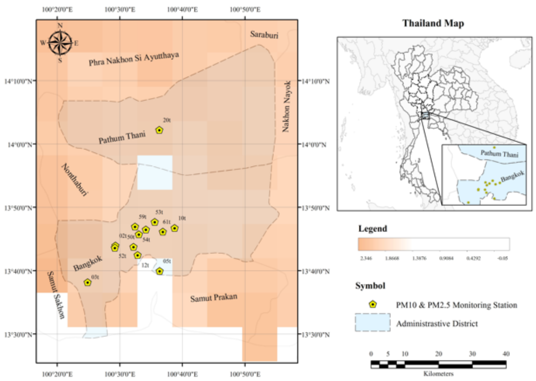


(j) PM2.5 of AOT (2020)

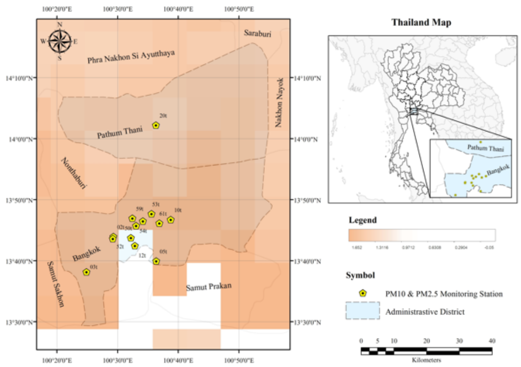
Fig. 3. The monthly average concentration of PM_{10} and $PM_{2.5}$ from AOT in BKK and PT from 2018 to 2020.

3.2 Relationship PM_{10}, $PM_{2.5}$ mass concentration and AOT

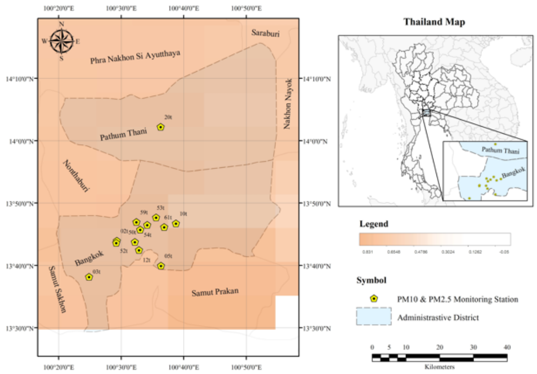
The correlation between PM_{10} and $PM_{2.5}$ concentrations and AOT values in study area stations was expressed by the correlation coefficient. The use of multi-year monthly mean MODIS-AOT in the site study from 2018 to 2020. This study presents a multi-year air analysis of PM_{10}, $PM_{2.5}$ air quality over a site study. Fig. 4 and S2 show images from MODIS. In Fig. 4, January is predominantly displayed as the maximum of PM_{10}, $PM_{2.5}$, and AOT levels. The Pearson correlation coefficient for PM_{10}, $PM_{2.5}$ concentrations, and AOT values at 13 stations are shown in Table 2. It was found that the correlation of PM_{10} and $PM_{2.5}$ at ground-based stations and PM_{10} and $PM_{2.5}$ from the aerosol optical thickness (AOT) retrieved by the MODIS-AOT reveals positive correlations with correlation coefficients (R^2) equal to 0.398 and 0.560 for PM_{10} and $PM_{2.5}$, respectively. Previous studies in Malaysia, Jamil et al. [15], and in Thailand, Somwandee et al. [28] used the correlation coefficient to study the relationship between PMs and AOT values. Their research reports used satellite data to estimate PM levels. Some research found a higher correlation between AOT and PM concentration than this study, such as Li et al. [29]. PM_{10} mass concentration from a monitoring station and MODIS-derived 500 m-resolution AOT show a linear regression (R^2 = 0.51) and Xu et al. 2016 [27 estimated PM by using MODIS data over in Yangtze Delta Region, China. The authors observed the ground-based samples from four and estimated the coarse and fine mass concentrations; this finding manifested positive results. The correlations of $PM_{2.5}$ were 0.48, 0.62, 0.61, and 0.52, respectively. While the correlation of PM_{10} showed 0.57, 0.56, 0.64, and 0.68, respectively. They reported that in the United State of America, the MODIS AOT has a strongly positive correlation with $PM_{2.5}$ levels (R = 0.7) at seven stations in Jefferson County, Alabama.



(a) January-2018

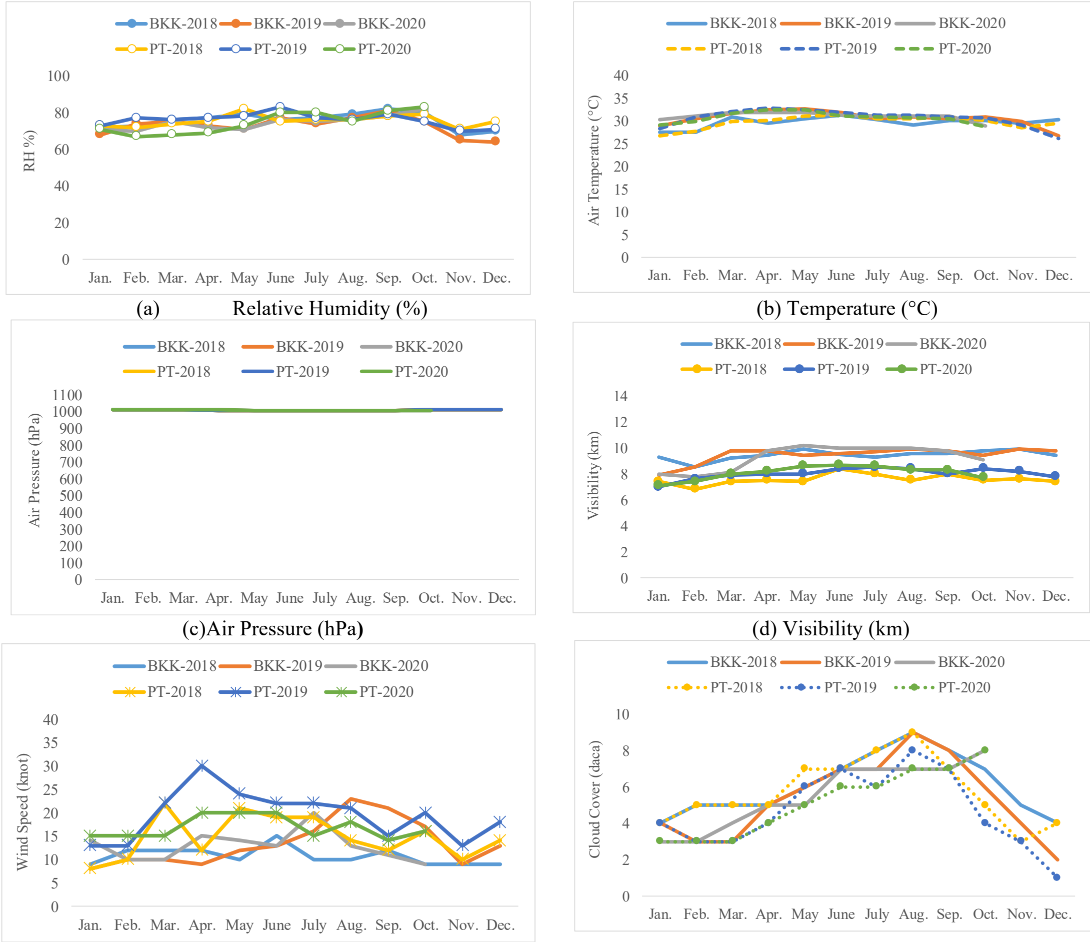


(b) January-2019



(c) January-2020

Fig. 4. Spatial distribution characteristics of multi-year monthly mean AOT in this study; (a) January-2018 (b) January-2019 and (c) January-2020.



(a) Relative Humidity (%)
(b) Temperature (°C)
(c)Air Pressure (hPa)
(d) Visibility (km)
(e) Wind Speed (knot)
(f) Cloud Cover (deca)

Fig. 5. The temporal and spatial distribution of meteorological, (2018 to 2020).

3.3 Correlation of PM_{10}, $PM_{2.5}$, AOT value with Meteorological Factor

This year-long study also considered the relationship of PM_{10}, $PM_{2.5}$, and AOT value with temperature (°C), relative humidity (%), pressure (P), visibility (Vis), wind speed (WS), and cloud cover (CC). Fig. 5 shows the temporal and seasonal variation of meteorological parameters based on monthly average in the BKK and PT site during the study period from 2018-2020. Overall, the meteorological parameters have a smaller value in the summer season than the winter season. Furthermore, the average temperature in BKK and PT was 28.10, 29.47, 31.17, 31.77, 31.97, 31.40, 30.80, 30.77, 30.70, 29.83, 28.85, 27.90°C and 28.90, 29.67, 31.40, 31.30, 31.70, 31.43, 30.63, 30.33, 30.53, 29.90, 29.70, 28.45°C. On the other hand, the meteorological parameters among the two study sites, that is relative humidity, pressure, wind speed and cloud cover, ranged from 70.00-79.83 %, 1006.17-1012.32 hPa, 7.77-9.10 km, 10.25-17.00 knot and 2.75-6.83 deca. The dispersion capacity of the atmospheric pressure, air temperature, and relative humidity were anticipated to influence PM_{10} and $PM_{2.5}$ concentrations, with high concentrations during low wind velocity, low temperature, and less intense sunshine. Wind, being a major meteorological component, has an impact on the horizontal and vertical transfer of air contaminants. The average PM_{10} and $PM_{2.5}$ values for different RH intervals often drop with rainfall. It was also found that rainfall did not influence the concentrations of PM_{10}.and $PM_{2.5}$. Table 3 shows that air pressure, temperature, relative humidity, and wind speed have a positive relationship with PM_{10} and $PM_{2.5}$. The results showed a significant relationship with the concentration of PM_{10}, with r = 0.414, 0.351, 0.298 and 0.254, respectively. While there is a significant relationship with concentration of $PM_{2.5}$, with r = 0.197, 0.215, 0.127 and 0.282, respectively. It shows similar results for AOT. The results indicate a stronger influence of temperature on PM_{10} and $PM_{2.5}$ than pressure, cloud cover, wind speed, and relative humidity, with the relationship gradually decreasing for PM_{10}, and $PM_{2.5}$. The correlation coefficient of temperature with PM is high for PM_{10} and $PM_{2.5}$, respectively. Similar results with Hien et al. [35] and Nguyen et al. [36], have been reporting that air temperature is an important determinant for their estimation of the $PM_{2.5}$ model. The relationships between PM_{10} and $PM_{2.5}$ concentrations and meteorological factors have been investigated in many studies. For example, meteorological data can influence the concentration and have a relationship between PM_{10}, $PM_{2.5}$, and AOT [37-42]. The Pearson correlation coefficients show a high positive relationship between pressure and temperature, relative humidity, visibility, and wind speed. These studies imply that those meteorological parameters are subject to direct variations. There were no differences in the average monthly values of each meteorological type. In contrast to Kwanma et al. [43], the relationship between pressure, temperature and relative humidity is inversely variable. Further, meteorological parameters could be obtained from the observation site.

3.4 Simple linear regression model for predicting

Simple regression analysis shows that air pressure, wind speeds, temperature, and relative humidity could affect and predict variation in PM_{10}, $PM_{2.5}$, and AOT concentrations, as presented in Table 4.

Table 3. The correlation coefficient for PM_{10}, $PM_{2.5}$ concentrations, AOT value, and meteorological parameters, respectively.

Parameter	PM_{10}	$PM_{2.5}$	PM_{10} AOT	$PM_{2.5}$ AOT	P	RH	T	WS	Vis	CC
PM_{10}	1									
$PM_{2.5}$	0.72**	1								
PM_{10} AOT	0.39**	0.33**	1							
$PM_{2.5}$ AOT	0.56**	0.55**	0.79**	1						
P	0.41**	0.19	0.17	0.28*	1					
RH	0.29*	0.12	0.08	0.13	0.97**	1				
T	0.35*	0.21	0.13	0.24*	0.97**	0.96**	1			
Vis	0.13	-0.25	0.06	0.12	0.90**	0.88	0.90**	1		
WS	0.25*	0.28*	0.01	0.00	0.58**	0.62**	0.64**	0.46**	1	
CC	-0.21	-0.36	-0.19	-4.10**	0.55**	0.67**	0.59**	0.62**	0.43**	1

Note: *$p < 0.05$, **$p < 0.01$

P= Pressure, RH = Relative humidity, T = Temperature, Vis = Visibility, WS = Wind speed, CC = Could cover

Table 4. Relationship of PM_{10}, $PM_{2.5}$, AOT and meteorological by Simple Linear Regression method.

Parameter	Simple Linear Regression	r	R^2	*p*-value	n
PM_{10} of AOT	PM_{10} = 27.117 + 0.111 PM_{10}AOT	0.40	0.16	0.00	468
	$PM_{2.5}$ = 12.771 + 0.54 PM_{10}AOT	0.33	0.11	0.00	468
$PM_{2.5}$ of AOT	PM_{10} = 18.544 + 0.505 $PM_{2.5}$AOT	0.56	0.31	0.00	468
	$PM_{2.5}$ = 7.051 + 0.292 $PM_{2.5}$AOT	0.55	0.31	0.00	468
Air pressure (P)	PM_{10} = -0.614 + 0.049P	0.41	0.17	0.00	72
	$PM_{2.5}$ = -0.291 + 0.015P	0.20	0.04	0.19	72
Relative Humidity (RH)	PM_{10} = 13.463 + 0.460RH	0.30	0.09	0.01	72
	$PM_{2.5}$ = 4.971 + 0.126RH	0.13	0.02	0.29	72
Air Temperature (T)	PM_{10} = 7.269 + 1.351T	0.35	0.12	0.00	72
	$PM_{2.5}$ = -1.247 + 0.527T	0.22	0.05	0.07	72
Wind Speed (WS)	PM_{10} = 29.189 + 1.215WS	0.25	0.07	0.03	72
	$PM_{2.5}$ = 1.954 + 0.860WS	0.28	0.08	0.01	72
Visibility (Vis)	PM_{10} = 31.925 + 1.726Vis	0.14	0.02	0.25	72
	$PM_{2.5}$ = 15.481 - 0.199Vis	0.03	0.001	0.83	72
Could Cover (CC)	PM_{10} = 59.230 - 2.527CC	0.21	0.04	0.08	72
	$PM_{2.5}$ = 28.338 - 2.817CC	0.36	0.13	0.00	72

Moreover, the results show that when the meteorological data are decreasing, such as pressure, wind speeds, temperature, and humidity, there an increasing in the level of coarse and fine particles, especially during the dry season. When the weather turns cold and relative humidity decreased, coarse and fine particle concentrations increased

3.5 Multiple linear regression models for predicting

Multiple regression analysis (MRA) with step-wise shows that meteorological factors affected PM_{10} concentration at 68.10%, with high relative values for pressure, RH, visibility and AOT, and $PM_{2.5}$ concentrations at 50.20%, with high relative values for wind speed and could cover, respectively ($p < 0.01$), as presented in Table 5. This study followed a similar trend to the research of Kwanma et al. [43], where air pressure and wind speed have a significant effect on variation of PM_{10} concentrations. Especially the dry season shows a higher PM_{10} level than the rainy based on their study.

Table 5. Relationship of PM_{10}, AOT and meteorological by Multiple Regression Analysis.

Parameter (predictor)	b	Beta	*t*-value	*p*-value
$PM_{2.5}$ of AOT	0.36	0.39	2.95	0.00
Pressure	0.28	2.44	5.59	0.00
Visibility	-13.68	-1.10	-6.29	0.00
Relative humidity	-1.75	-1.13	-3.10	0.00
PM_{10} of AOT	-0.06	-025	-2.25	0.03
Constant	-0.06	-	-0.01	0.99
R = 0.83 R^2 = 0.68 F = 28.24 *p* value < 0.001				
$PM_{2.5}$ of AOT	0.37	0.64	4.22	0.00
PM_{10} of AOT	-0.07	-0.44	-3.17	0.00
Wind speed	1.38	0.45	4.56	0.00
Could cover	-2.96	0.87	-3.41	0.00
Constant	2.75	-	0.50	0.62
R = 0.71 R^2 = 0.50 F = 16.86 *p* value < 0.001				

4. Conclusion

The result shows the temporal and spatial distribution of PM_{10} and $PM_{2.5}$ concentrations. There were significant differences between average monthly PM_{10} and $PM_{2.5}$ concentrations (p-value < 0.05). All stations show trends toward large concentrations in the dry season during the study period from 2018-2020. The monthly average PM_{10} and $PM_{2.5}$ showed higher concentrations in the BKK than in the PT. The seasonal variation influenced the PM_{10} and $PM_{2.5}$ concentrations.

Positive associations were found between PM_{10}, $PM_{2.5}$, and AOT concentrations. The results reveal positive correlations between PM_{10}, $PM_{2.5}$, and AOT concentrations, with correlation coefficients (R2) equal to 0.398 and 0.560 for PM_{10} and $PM_{2.5}$, respectively. The Pearson correlation coefficients are small, even showing the positive trends. The limitations of MODIS AOT were observed during the study period. This study discovered that meteorological conditions influenced the dispersion of PM_{10} and $PM_{2.5}$. Multiple regression analysis (MRA) with step-wise shows that meteorological factors affected on PM_{10} concentration at 68.10% with high relative for pressure, humidity, visibility, and AOT, and $PM_{2.5}$ concentrations at 50.20% with high relative for wind speed. Surface coarse and fine particle concentrations in research regions can be estimated using BKK and PT stations.

Acknowledgements

The author is appreciative for the financial assistance offered by Faculty of Science and Technology, contract No. SciGR28/2563 by Faculty of Science, Thammasat University (TU). The author is grateful to all official organizations that have thoughtfully discussed and support this effort.

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Appendix

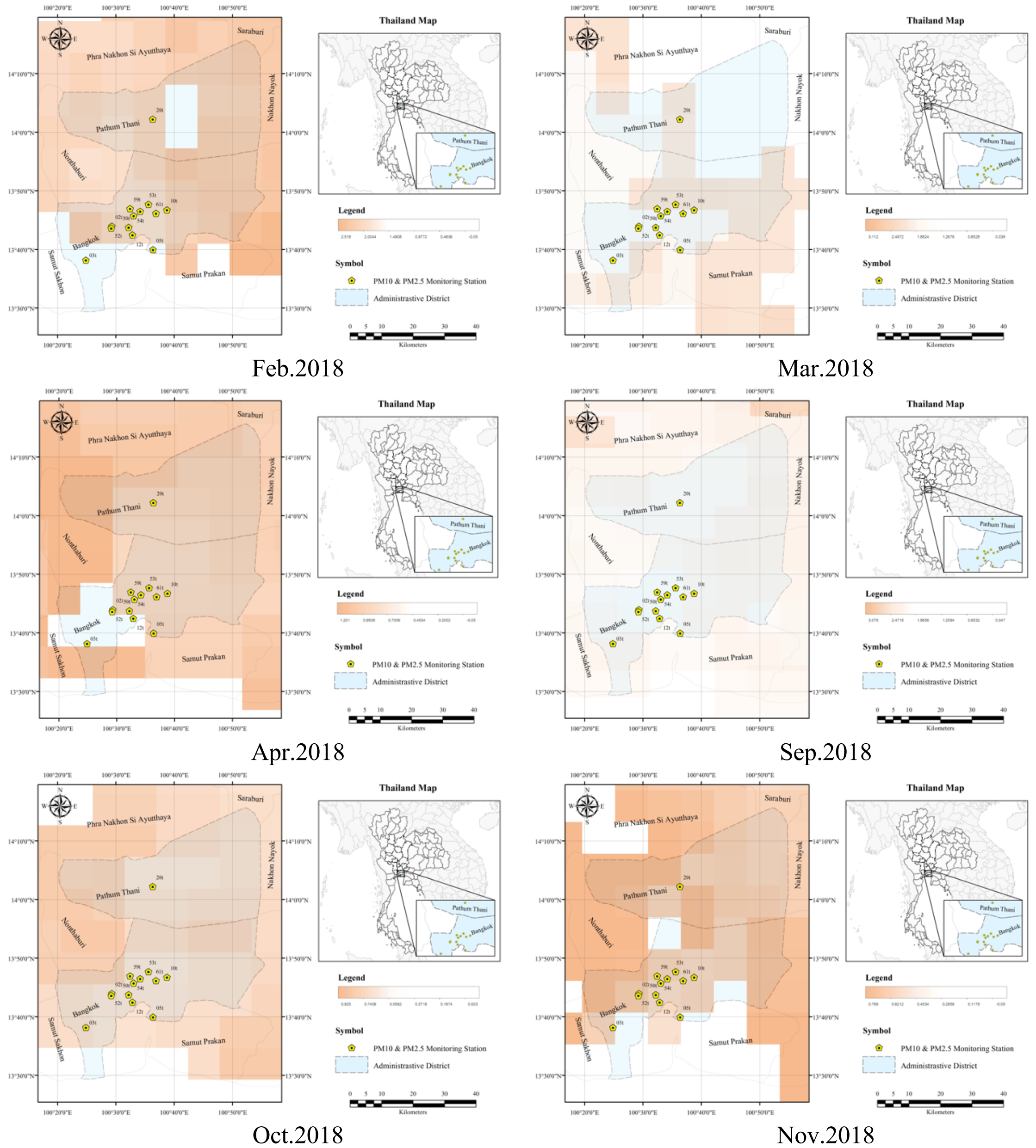
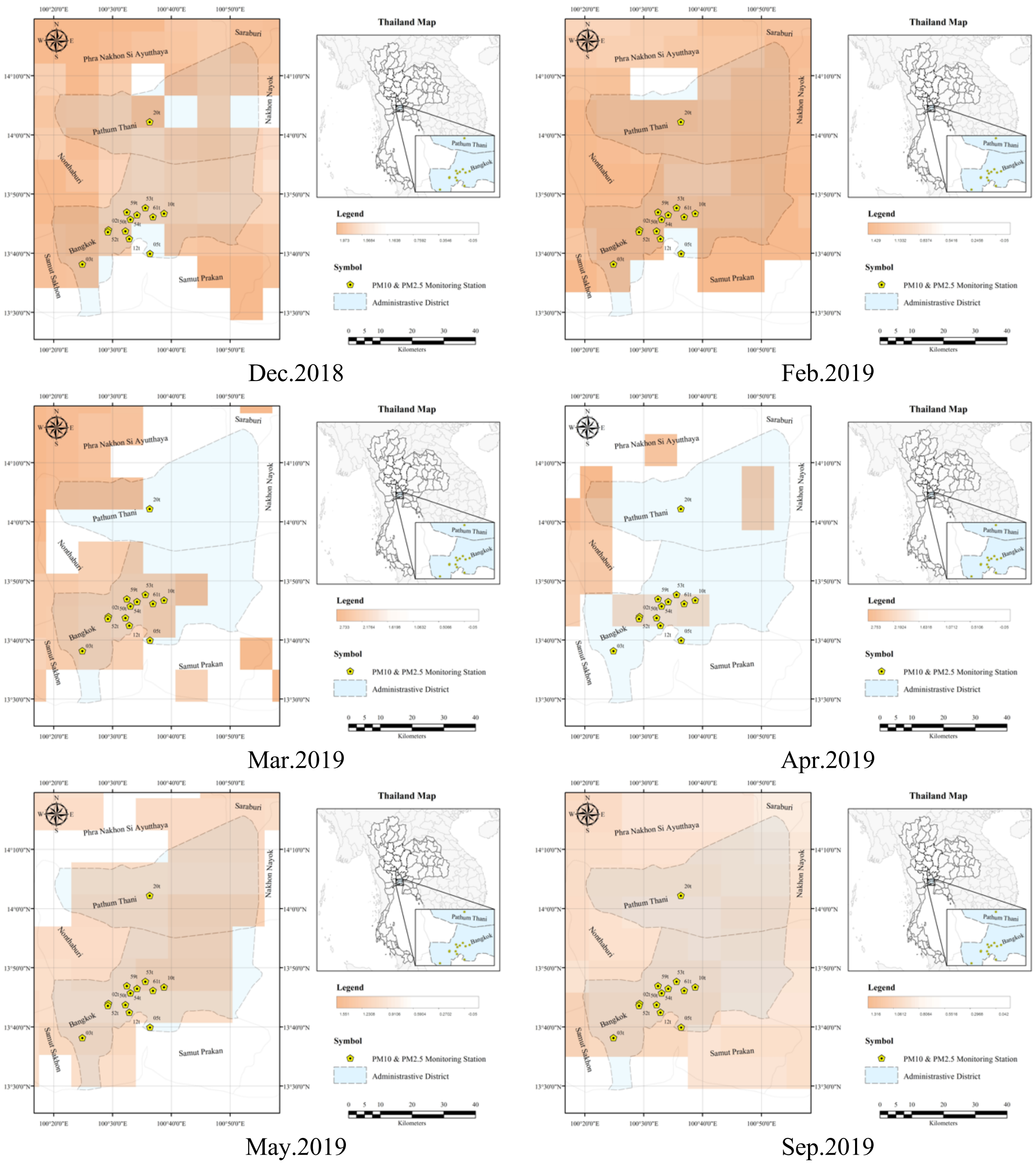


Fig. S2. Spatial distribution characteristics of multi-year monthly average AOT in BMR from 2018 to 2020.



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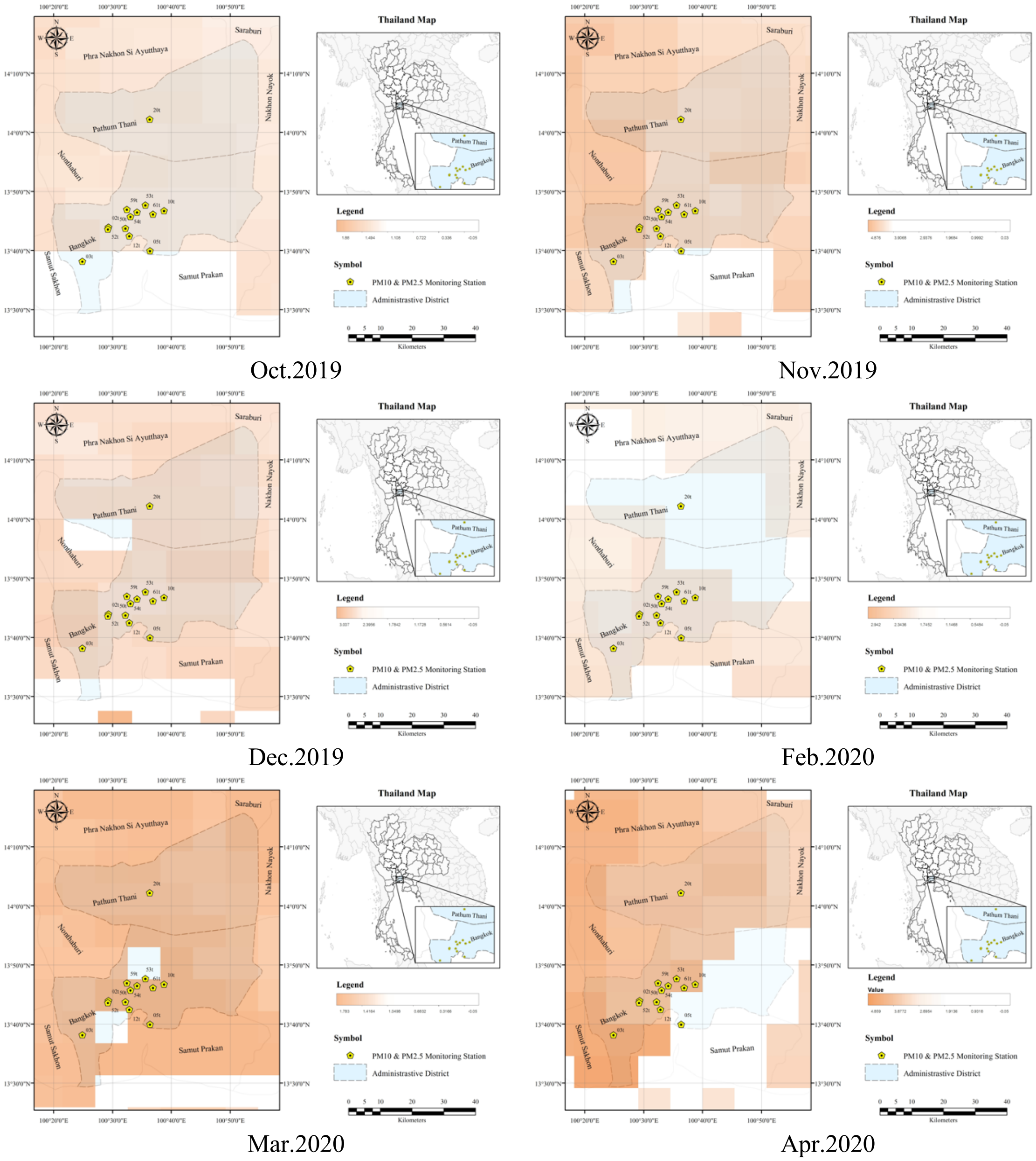

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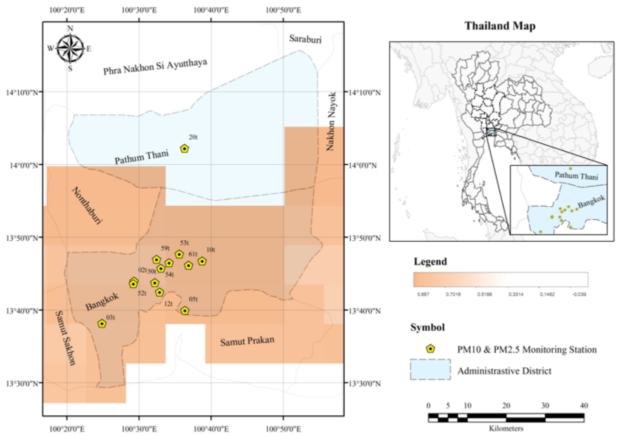

May.2020

Fig. S2. Spatial distribution characteristics of multi-year monthly average AOT in BMR from 2018 to 2020 (cont.).