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Social Restriction Effects on Air Pollution: How the $PM_{2.5}$ Concentration Changed with Lockdown Management of COVID-19 Pandemic Control in Bangkok Thailand

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Abstract

Under rapid proceeding of COVID-19 pandemic, Thailand government announced lockdown and social restriction in March 2020. With the frustration of pandemic, anthropogenic etiology of air pollution was beneficially assessed on other hands. The study aims at exploring how $PM_{2.5}$ concentration changed with lockdown management and social restriction as part of COVID-19 control in the Bangkok Metropolitan Region, Thailand. There was $PM_{2.5}$ concentration reduction of roadside (18.6%) and ambient (9.2%) in COVID-19 lockdown period than the same months of previous consecutive year. Moreover, this study showed a clear decline of $PM_{2.5}$ during lockdown in both rush and non-rush hours except one roadside area which has a non-significant rising $PM_{2.5}$ because of trucks activities in some area. Additionally, the probable high concentration during the lockdowns period occurred at calm wind speed, mostly from the south direction, particularly in roadside area indicating the traffic source of $PM_{2.5}$ in the Conditional Bivariate Probability Function (CBPF) plot which estimate probable direction and source of air pollutant. Although $PM_{2.5}$ is significantly reduced in the lockdown period, it is still above 66% (33 microgram per cubic meter) of the Thailand standard in CBPF analysis. No specific minimum level of $PM_{2.5}$ is safe for health. However, it highlights monitoring emission sources and encouraging the community to make concerns about their daily contributing activities of air pollution.

Keywords: PM2.5; CBPF; COVID-19; Bangkok Metropolitan Region (BMR); Thailand

1. Introduction

The Coronavirus disease formerly named 2019-nCoV started as a cluster case of Pneumonia in Wuhan, China, in December 2019 (Zhu *et al.,* 2020). Coronavirus disease (COVID-19) was regarded as a pandemic disease by the World Health Organization (WHO) on March 11, 2020, after the drastically increasing case number and deaths in many countries. To interrupt the COVID-19 transmission, WHO recommended the social restriction and ban of unnecessary traveling (World Health Organization, 2020).Thailand detected the first COVID-19 case on January 13, 2020, and recommended social distancing

(DDC Thailand, 2020b). After the outbreak had happened, Bangkok activated partial lockdown to reduce social contact starting from March 22, 2020. The work from home and online learning activities were introduced to restrict social activities. International and local flights were stopped, and interprovincial traveling was temporarily closed (DDC Thailand, 2020a).

Air pollution contributed substantially to the global burden of disease, with an increasing trend in non-communicable diseases, particularly in low and middle-income countries (Cohen *et al.,* 2017). Thailand has 347 areas with high Traffic Congestion Index (TCI) > 0.8, including Bangkok province (TCI > 1). TCI is calculating traffic congestion in a location by proportion of traffic volume and highway capacity. Bangkok has TCI > 1 means traffic volume is highly congested than the highway lanes capacity. (Department of Highways, 2019). Vehicle emission and fossil fuel combustion mainly contribute to particulate matter formation providing health impacts in prolonged exposure (Mukherjee & Agrawal, 2017). Bangkok has suffered from roadside air pollution in which trucks are the significant contributor to particulate matter, NOx, and SO_2 formation (Cheewaphongphan *et al.,* 2017). Vehicle's emission is one of the main sources of black carbon. It has poor impact on climate change and human health such as cancer, respiratory and cardiac problems (U.S. EPA., 2011). The fine particulate matter around Bangkok urban area has a higher mass of black carbon (Wimolwattanapun, Hopke, and Pongkiatkul, 2011). Thailand state of pollution report 2018 highlighted the instability of air pollutants, of which $PM_{2.5}$ exceeding 24 - hour average standard (> 50 µg/m^3) was observed over 20% of the days per year in Bangkok (Pollution Control Department, Ministry of Natural Resources and Environment, 2019).

The anthropogenic activities contributed to poor air quality. There were several studies of air quality and social restriction lockdown management. Northern China had 5.93% reductions in $PM_{2.5}$, after social restriction and traveling were banned during COVID-19 pandemic (Bao & Zhang, 2020). The partial and total lockdown effects on $PM_{2.5}$ showed significant reduction of $PM_{2.5}$, PM_{10}, benzene, CO, NOx, and BC in Milan city (Collivignarelli *et al.,* 2020). The study of pollutants and air quality after starting pandemic observed 17.78% PM2.5 reductions in some provinces of China, and 1.10% in some study states of USA (Shakoor *et al.,* 2020). Besides, $PM_{2.5}$ concentrations were reduced with lockdown by 35% in Wuhan, 29% in Hubei (Wuhan excluded), and 19% in China (Hubei excluded) (Chu *et al,* 2021; He *et al* 2020). Although vehicle emission had decreased in Ontario, Canada, residential source such as outdoor cooking during lockdown provided no significant changes of fine particle (Adams, 2020). It proposed the considering of different $PM_{2.5}$ sources in pollution control.

This will be a good example of the correlation between specific human behavioral shifts and air quality. It is impossible to stop neither the factories nor the permanent restriction of people's activities. However, it will be highly beneficial for air quality management by highlighting $PM_{2.5}$ difference between the regular and social restriction periods. Thailand is focusing on using clean vehicles to reduce emissions by collaborating with the UN environment (UN Environment Programme, 2019). The green community can be developed if non-essential population motilities are reduced, but not disturbing the economy. The purpose of this study is how the $PM_{2.5}$ concentration changed with lockdown management and social restriction of COVID-19 pandemic control in the Bangkok Metropolitan Region, Thailand.

2. Material and method

2.1 Study area and period

Bangkok has already suffered from air pollution for a long time and is the most crowded with traffic-congested city in Thailand, 33rd in the world (INRIX, 2019). Besides, the weather conditions disturb pollutant dispersion and aggravate air pollution. In Bangkok Metropolitan Region (BMR), traffic congestion and biomass burning contributed to the endangered level of $PM_{2.5}$ (Narita *et al.,* 2019). It is advantageous to highlight the traveling restriction during the COVID-19 pandemic lockdown period that might affect the $PM_{2.5}$ level in Bangkok. The third phase of lockdown was released at the end of May starting some work and school activities with strict precautions. Therefore, March to May duration is the most appropriate time to study the lockdown impacts on air pollution.

2.2 Meteorological and $PM_{2.5}$ data sources

Bangkok has a tropical monsoon climate, an annual average temperature of 28.1°C, and 56.3 inches of precipitation. Thailand designated the ambient air quality standard of $PM_{2.5}$, 50 μg/m^3 for 24-hour average and 25 μg/m^3 for annual average. Ground level observation of $PM_{2.5}$ from four ambient and four roadside stations by the Pollution Control Department (PCD) Thailand were analyzed in this study. $PM_{2.5}$ is measured by Beta-ray attenuation method, following the United States Environmental Protection Agency (USEPA) reference, federal equivalent method. $PM_{2.5}$ is measured on hourly basis for whole year. The roadside stations are located within 10 m to main roads, and ambient stations are placed about 50 m away from main roads. The data included March to May of 2019 and 2020 as a comparative data of pre-lockdown and lockdown periods for $PM_{2.5}$ level. The concentration of $PM_{2.5}$ was regarded as 7.00-10.00 hours and 16.00-19.00 hours for rush times and 11.00-14.00 hours for non-rush times. The difference between the mean $PM_{2.5}$ concentrations of 2019 and 2020 (March-May) was compared by using independent t-test with a statistically significant p value < 0.05. The percent changes in average concentration were determined as follows.

$$Percent\ Difference =$$

$$\frac{(average\ PM2.5\ in\ 2020 - average\ PM2.5\ in\ 2019)}{average\ PM2.5\ in\ 2019} * 100$$

2.3 Air Quality Guidelines for PM2.5

Thailand's National Ambient Air Quality Standard (NAAQS) of $PM_{2.5}$ are 50 μg/m^3 for the 24-hour average concentration and 25 μg/m^3 for the annual average concentration (TransportPolicy.net, 2019). Environmental Performance Indicators (EPI) described in New Zealand air quality guideline is applied in this study to support the sustainable air quality management (Table 2). EPI program includes five categories of excellent, good, acceptable, alert and action for air quality management based on the monitoring pollutant concentration. It predicts required action to prevent rising of unhealthy level of air pollutant. For example, measured concentration of over 66% of the Thailand $PM_{2.5}$ standard is categorized as alert level for health that needed to take action for reducing pollutant emission (New Zealand. Ministry for the Environment, 2002) (Jindamanee *et al.,* 2020).

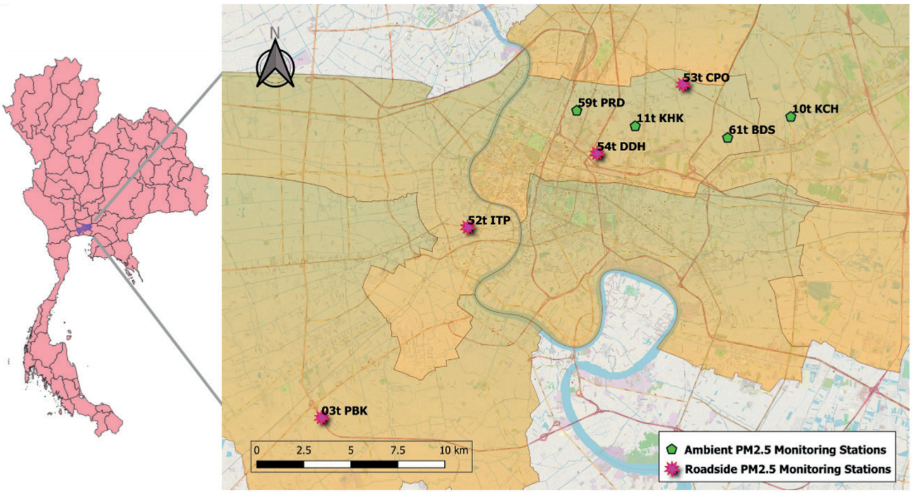


Figure 1. Map showing monitoring stations for $PM_{2.5}$ in Bangkok Metropolitan Region, Thailand

Table 1. Description of PM2.5 monitoring stations and coordinates

Code	Monitoring station Name	Area Type	Coordinates (UTM) x	Coordinates (UTM) y
10t KCH	Klongchan Housing	Ambient	677905.4	1523953
11t KHK	Huakwang Housing	Ambient	669641.9	1523453
59t PRD	The Public Relation Department	Ambient	666535.7	1524277
61t BDS	Bodindecha School	Ambient	674550.7	1522834
03t PBK	Kanchanaphisek Bang Khun Thian	Roadside	652978.2	1507972
52t ITP	Thonburi Power Sub-Station	Roadside	660743	1518091
53t CPO	Chokchai Police Office	Roadside	672189.3	1525671
54t DDH	Dindang Housing	Roadside	667613.4	1522012

Table 2. Environmental Performance Indicator (EPI) programme air quality categories

Category	**Measured data**	**Comment**
Action	Exceeds the guideline value	Exceedances of the guideline are a cause for concern and warrant action, particularly if they occur on a regular basis.
Alert	66%-100% of the guideline value	This warning level, which can lead to exceedances if trends are not curbed.
Acceptable	33% - 66% of the guide value	This a broad category, where maximum values might be of concern is some sensitive locations but are generally at a level that doesn't warrant urgent action.
Good	10% - 33% of the guideline value	Peak measurements in the range are unlikely to affect air quality.
Excellent	< 10% of the guideline value	Of little concern: if maximum values are less than a 10th of the guideline, average values are likely to be much less.

Source: (New Zealand. Ministry for the Environment, 2002)

2.4 Conditional Bivariate Probability Function (CBPF)

The CBPF locates the probability of the occurrence of high $PM_{2.5}$ concentrations at different wind speed and wind direction. The bivariate polar plot uses the wind speed as a third variable. It is graphically allocating in polar coordinates determining probability of high $PM_{2.5}$ sources. Polar coordinates describe the location of the source in terms of possible distance and angle direction of source. In this study, the mean concentration of $PM_{2.5}$ is calculated within specific wind speed-interval and direction and is illustrated in the CBPF. The dispersion characteristics of $PM_{2.5}$ are analyzed against the wind factors in the open-air package of R software-version 4.0.2 (Carslaw & Ropkins, 2012, 2020). The $m_{\Delta\theta}$ is $PM_{2.5}$ samples that increase above national standard level, C is the concentration of $m_{\Delta\theta}$ samples of occurrence exceeding the 66% of standard level (x), in a certain wind sector of Δθ with wind speed interval Δμ. In the same way, $n_{\Delta\theta,\Delta\mu}$ is the total number of $PM_{2.5}$ samples (Uria-Tellaetxe & Carslaw, 2014). The bivariate polar plot displays how the $PM_{2.5}$ level will change with wind speed and interval depending on local or far sources as equation below;

$$CBPF_{\Delta\theta,\Delta\mu} = \frac{m_{\Delta\theta,\Delta\mu|C\geq x}}{n_{\Delta\theta,\Delta\mu}}$$

2.5 Hybrid Single-Particle Lagrangian Integrated Trajectory model

The National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) simulate the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) which determine the atmospheric transport and dispersion (Stein *et al.*, 2015). Backward-trajectory analysis is used in this study to support the description of origin and transportation of $PM_{2.5}$.

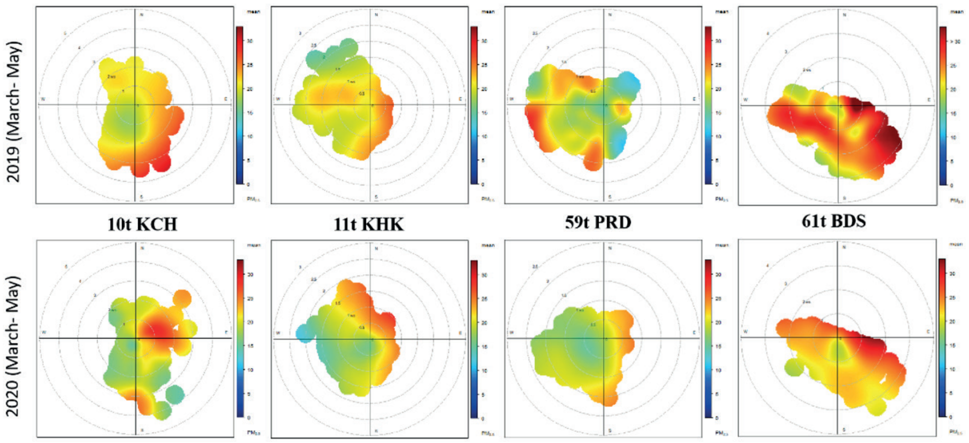
3. Results and discussion

3.1 Determining probable high concentration of source direction.

The probability of a high $PM_{2.5}$ emission source is illustrated using conditional bivariate probability functions (CBPF). $PM_{2.5}$ risk level is categorized into five groups from excellent to needs action through New Zealand air quality guidelines. In which, above 66% of the standard level is high risk of exceeding the threshold. CBPF plots for ambient $PM_{2.5}$ indicated that high concentration (> 66% of standard: 33 µg/m^3) predominantly coming from the south, southeast, and southwest in March to May of 2019 (Figure 2). The probable high level occurred at 2-3.5 m/s of wind speeds, apart from one station at < 1 m/s, and observed at the peripheral of stations. In 2020, the probable high concentration of $PM_{2.5}$ was centralized at monitoring stations with a range of 0.5-2.5 m/s wind speed coming mostly from the south, southeast, and east.

Similarly, CBPF plots for the roadside $PM_{2.5}$ showed a high concentration dominantly from the south, west, and east in 2019 from March to May (Figure 3). The probable alert level $PM_{2.5}$ concentrations occurred at 1-5 m/s of wind speeds and located peripheral to monitoring stations. In 2020, the probable high concentration was captured near the stations at 0-3 m/s of calm wind speed together with the south, west, and north wind. Because of the COVID-19 lockdown effect, people's activities were reduced, producing low pollutants in the environment. However, 1 out of 4 roadside stations showed high concentration even in the lockdown period because of some trucks for economic transportation. Likewise, New York city where air pollutant concentrations had no obvious changes of air quality in the lockdown period (Zangari, *et al.,* 2020).

Based on the EPI, $PM_{2.5}$ over 33 µg/m^3 is an alert level for action taken to reduce pollutant emission. The polar plots showed alert levels of $PM_{2.5}$ concentrations for all stations, particularly at high and low wind speed in pre-lockdown, and low wind speed in lockdown periods. $PM_{2.5}$ monitoring stations are in central Bangkok and many people are at high risk of breathing polluted air precipitating $PM_{2.5}$ related health problems.



Note: Wind speed in m/s is expressed in radial axis and color scale is the concentration of $PM_{2.5}$ µg/m^3 with maximum expression of 66% of the standard of Thailand. All the CBPF plots are displayed for hourly $PM_{2.5}$ data of 2019 and 2020 (March-May). Name of monitoring stations are fully described in table 1.

Figure 2. Bivariate polar plots of ambient $PM_{2.5}$ concentrations before and after lockdown activities of COVID-19 at Bangkok, Thailand (2019-2020).

3.2 $PM_{2.5}$ concentrations based on the lockdown condition

The average 24-hr $PM_{2.5}$ concentrations during lockdown reduced about 5.2% -13.4% than pre-lockdown period in ambient stations. Similarly, there were lower concentrations of $PM_{2.5}$ during lockdown (about 4.4% - 27.5%) for roadside stations. In overall, 24-hr mean $PM_{2.5}$ was reduced 9.2% in all ambient stations and 18.6% in all roadside stations with lockdown phase. During the rush-hours (7.00-10.00, 16.00-19.00 hours), $PM_{2.5}$ reductions was 5.6% - 12.5% in ambient stations, while roadside $PM_{2.5}$ decreased by 7.8% - 25.5% in lockdown months. Moreover, non-rush hours (11.00-14.00 hours) had 1.7% - 11.3% decreasing for ambient $PM_{2.5}$, and about 18.6% - 21.5% reduction in roadside $PM_{2.5}$ during lockdown times. Overall mean $PM_{2.5}$ had 9.4% (rush-hours), 8.2% (non-rush hours) reduction in all ambient stations and 18.7% (rush-hours), 14.1% (non-rush hours) decline in all roadside stations during the lockdown phase. Average 24-hr, rush and non-rush hours $PM_{2.5}$ had dropped during lockdown than pre-lockdown months, particularly roadside $PM_{2.5}$ concentrations. Percentage of $PM_{2.5}$ reductions during the lock down period found in this study is very much smaller than those reported in the study conducted in India which reported the nationwide $PM_{2.5}$ concentration decreasing by 43% during the lockdown period (Sharma *et al.,* 2020).

It should be noted that at Dindang Housing (DDH), the roadside station in central Bangkok had 3.6% increasing $PM_{2.5}$ in non-rush hours of lockdown. This can be explained as a result of special commuting permit of heavy-duty trucks into the city around 9.00-15.00 hours during the lock down period as compare with the normal period when the truck are not allowed to enter the city during that time. The trucks, light motor cars, and motorcycles are the main contributing factors for $PM_{2.5}$, black carbon and organic carbon fractions (Cheewaphongphan *et al.,* 2017).

3.3 Difference in $PM_{2.5}$ concentrations between 2019 (non-COVID) and 2020 (COVID)

Independent t test was calculated to compare the mean $PM_{2.5}$ concentrations between non-COVID and COVID lockdown period. Results revealed that the 24-hour mean ambient $PM_{2.5}$ concentrations was significantly reduced in 2020 than 2019 (20.7 ± 9.1, 18.8 ± 8.8, $p < 0.05$). Analytical results for roadside 24-hour $PM_{2.5}$ also had highly significant difference between 2020 and 2019 study period (27.5 ± 12.6, 22.4 ± 11.7, $p < 0.05$) (Table 3). Moreover, rush and non-rush hours of the lockdown days in most of the stations showed a significant decline of $PM_{2.5}$ concentrations than pre-lockdown days. While rush and non-rush hours of the day were separately analyzed

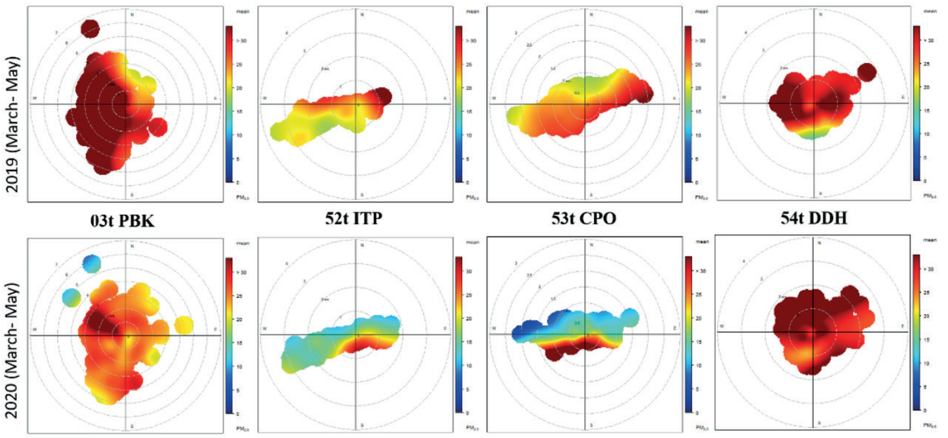


Figure 3. Bivariate polar plots of roadside $PM_{2.5}$ concentrations before and after lockdown activities of COVID-19 at Bangkok, Thailand (2019-2020).

for 2020 and 2019, one roadside station located in the crowded central area had no significant difference of $PM_{2.5}$ (32.1 ± 9.9, 31 ± 11.6, p 0.17). This was due to the fact that the heavy and light truck's activities were not turn-down dramatically during the lockdown days despite the social restriction.

$PM_{2.5}$ plays a contributing role in morbidity and mortality of respiratory illness, cardiovascular diseases, and cancer. High $PM_{2.5}$ is harm to human health ranging from cough, asthmatic attack, headache to even death prematurely (Du, *et al.,* 2016). The susceptible population particularly, young and elderly ages and people with long-term illnesses are vulnerable to the effects of $PM_{2.5}$. The concentration of $PM_{2.5}$ for roadside and ambient stations displayed a prominent rise in the pre-lockdown period (Figure 3 and 4). Although mean $PM_{2.5}$ was statistically significant dropped down during the lockdown period and below the NAAQS 24-hour standard 50 µg/m³, it was still higher than the WHO 24-hour standard guideline of 25 µg/m³ (World Health Organization, 2006). Most of the roadside stations had touched around 66% of Thailand 24-hour standard level and it alarmed the needs of action for preventing further progress.

Table 3. $PM_{2.5}$ levels in regular hours, rush hours, and non-rush hours in non-COVID and COVID times

Stations	2019 ^{a}	2020 ^{b}	p-value
Ambient station			
Ambient (24-hr) *	20.7 ± 9.1	18.8 ± 8.8	< 0.05
Ambient (Rush hours) *	21.8 ± 9.0	19.8 ± 8.8	< 0.05
Ambient (Non-rush hours) *	23.5 ± 9.9	21.6 ± 8.6	< 0.05
Klongchan Housing (24-hr)*	19.2 ± 8.7	17.9 ± 8.3	< 0.05
Huakwang Housing (24-hr)*	21.1 ± 7.8	18.3 ± 8.1	< 0.05
The Public Relation Department (24-hr)*	19.0 ± 10.1	18.0 ± 10.0	.001
Bodindecha School (24-hr)*	23.5 ± 8.9	20.9 ± 8.2	< 0.05
Roadside Station			
Roadside (24-hrs) *	27.5 ± 12.6	22.4 ± 11.7	< 0.05
Roadside (Rush hours) *	29.6 ± 13.0	24.1 ± 11.3	< 0.05
Roadside (Non-rush hours) *	30.5 ± 13.5	26.2 ± 11.6	< 0.05
Kanchanaphisek Bang Khun Thian (24-hr)*	35.8 ± 13.8	25.9 ± 13.6	< 0.05
Thonburi Power Sub-Station (24-hr)*	21.1 ± 9.3	16.5 ± 5	< 0.05
Chokchai Police Office (24-hr)*	22.6 ± 8.9	18.0 ± 10.2	< 0.05
Dindang Housing (24-hr)*	30.7 ± 11.7	29.3 ± 10.7	< 0.05

^{a} Average $PM_{2.5}$ concentration during in 2019 March-May without social restriction

^{b} Average $PM_{2.5}$ concentration during in 2020 March-May with social restriction

Note: The numbers are expressed as mean ± (SD). *Average $PM_{2.5}$ concentration is regarded as significantly different at p value < 0.05 with 95% confidence level.

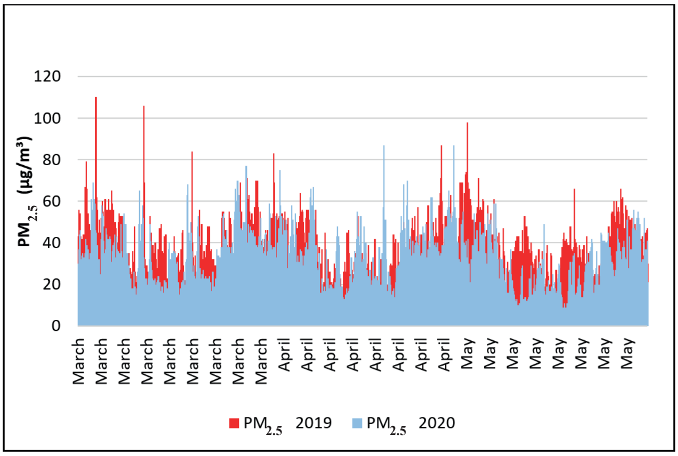


Figure 4. PM$_{2.5}$ concentrations at roadside stations during pre-lockdown and lockdown periods

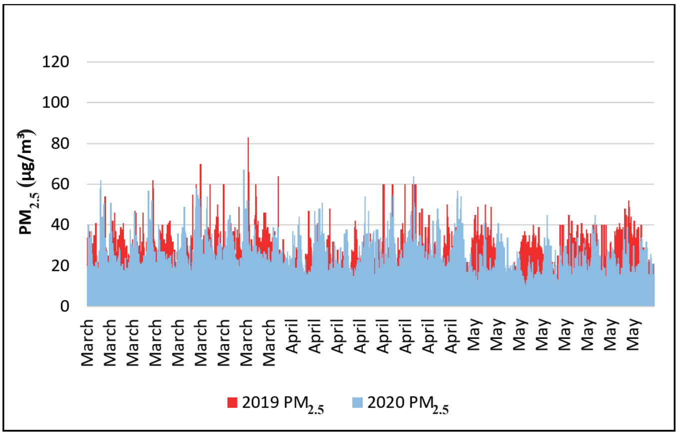


Figure 5. PM$_{2.5}$ concentrations at ambient stations during pre-lockdown and lockdown periods

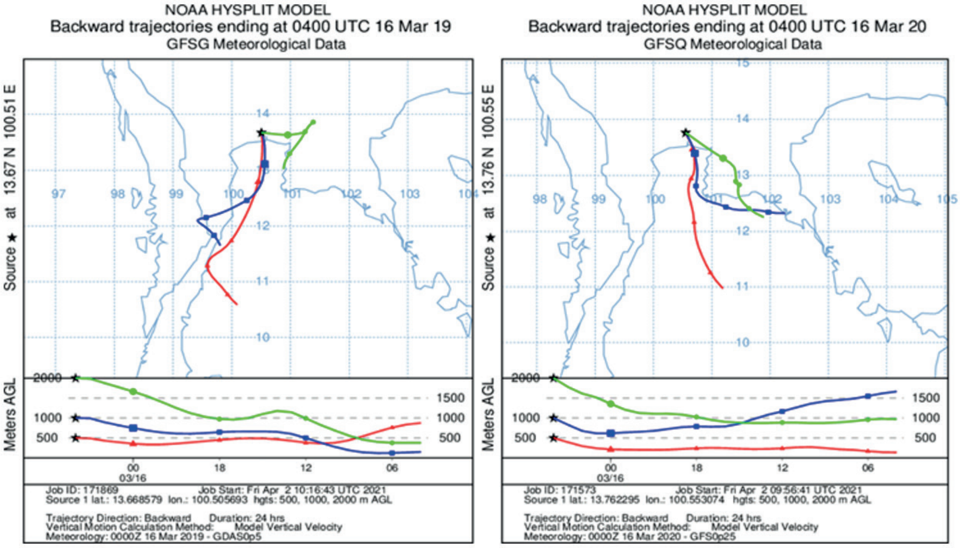


Figure 6. Backward 24-hour trajectories at 500, 1000, 2000 m above ground level by using HYSPLIT trajectory model-Air Resources Laboratory

The 24-hour backward trajectory analysis is applied to confirm the results obtained from CBPF analysis. To serve this purpose, the NOAA-HYSPLIT model was simulated to illustrate the traveling of air mass at Bangkok on 16 March 2021 and 16 March 2021 (as selected days). Results revealed that the wind directions at 500, 1000 and 2000 m above ground level (AGL) were prevailed from the south direction. These results indicated the same meteorological characteristics during the normal and lock down periods. Therefore, differences in $PM_{2.5}$ concentrations in these periods should be mainly resulted from different in amount of emissions.

4. Conclusion

The pandemic COVID-19 created a decrease in employment and delayed the country's development. Many people are staying at home and they may feel frustrated about losing their job. But, on the other side, $PM_{2.5}$ concentrations were decline during the lockdown period than regular time. Analyzed into the rush and non-rush hours, some stations had only small changes in the roadside because of trucks on the city road during the lockdown phase. The probable high concentration comes mostly from the south direction and occurred at calm wind during lockdowns than the pre-lockdown period for roadside and ambient stations. The source is located near to the stations and recorded high-level $PM_{2.5}$ is more prominent at roadside area. Although $PM_{2.5}$ is significantly declining in the lockdown period, CBPF plots of some stations still touch the alert level of Thailand NAAQS. It is a warning category needed action to prevent rising unhealthy levels of $PM_{2.5}$. The results highlight monitoring emission sources, encouraging the community to make concerns about their daily contributing actions of air pollution. This is a big challenge to improve air quality by changing individually for future generations. No specific level of $PM_{2.5}$ is safe for the health of people. However, but it makes the advantages of increasing awareness of careless human activities and environmental health problems.

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