An Approach of Statistical Analysis and Interpretation of PM2.5 Concentration based on Meteorological Factors and Temperature Effects in Bangkok, Thailand

Chalisa Veesommai Sillberg[a], Thitima Rungratanaubon[a,b*],
Surat Bualert[a,b], Parkpoom Choomanee[a,b] and Orathai Chueytawarit[a]

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Abstract

Currently, air pollution is an ongoing problem in Bangkok. In particular, fine particulate matter (PM2.5, diameter > 2.5 μm) and meteorological changes have increased the severity of air pollution causing public health and environmental concerns. Therefore, the objective of this research was to study the meteorological factors influencing changes in the PM2.5 concentration in Bangkok. The relationships were tested statistically between the PM2.5 concentration and meteorological factors (relative humidity, wind direction, wind speed, temperature, and air pressure); the correlation coefficients were -0.270, -0.127, -0.013, –0.130, and 0.084, respectively. In particular, relative humidity accounted for approximately 64.20% of the annual variation in PM2.5 during the high PM2.5 concentrations in winter and during rush hours. Furthermore, the occurrence of a temperature inversion (TI) affected the concentration of PM2.5 during the 4 years of the study period (2016 and 2018-2020). There was a trend for increasing PM2.5 concentration during longer periods of TI. The highest TI occurred during 2020, followed by 2016, 2019, and 2018, respectively.

Keywords: Statistical analysis, Particulate matter 2.5 (PM2.5), Meteorological factor, Temperature inversion, Environmental and information analysis

Introduction

Air pollution is a very serious environmental problem in Bangkok, Thailand, where it is ongoing and increasing in severity. In particular, the PM2.5 level has a concurrent and broad impact on public health, the environment and society. Bangkok has a thriving Central Business District (CBD), with high levels of economic and social activities that are driving increases in the population, land use and activities, which in turn increase PM2.5 sources and in particular, diesel engines in vehicles. In addition, meteorological parameters are crucial factors affecting the concentration and pattern of PM2.5 distribution (Kwanma et al., 2019; Narita et al., 2019). With stable atmospheric conditions, there is a lack of vertical air movement. The characteristics of some meteorological parameters change with altitude and those characteristics can impact the concentration and pattern of PM2.5 distribution (Choomanee et al., 2020). In addition, movement in the PM2.5 distribution between areas is affected by increasing relative humidity, while an increase in temperature, according to the altitude can affect meteorological characteristics, resulting in the accumulation of PM2.5 in the area. At certain times in Bangkok, air quality is influenced by the long-distance movement of PM2.5 (Chakrit and Duangnapha, 2018) and an increase in relative humidity (70-100%) that results in a decrease in the amount and concentration of PM2.5. Furthermore, wind speed and temperature factors affect the concentration and distribution of PM2.5 both horizontally and vertically. When the wind speed decreases and the local temperature lowers, the rate discharge of PM2.5 decreases (Rungratanaubon et al., 2018; Sivarin et al., 2013).

Therefore, this research aimed to study the meteorological factors that affect concentration chang-

[a] Department of Environmental Science, Faculty of Environment, Kasetsart University, 10900, Thailand.
[b] The Monitoring of Microclimate and Air Pollution in Thailand Project, Kasetsart University, 10900, Thailand
*Corresponding author email: thitima.r@ku.th

es in the PM2.5 distribution in Bangkok. The results of this study will contribute to guidelines for sustainable management and addressing the problem of PM2.5.

2. Methodology

2.1 Study area

Bangkok has a large urban area, consisting of residential areas and high-rise buildings (67.36%), agricultural areas (26.67%), green areas (0.16%), water areas (0.96%), and miscellaneous areas (5.85%). All areas include many kinds of human activity that can be sources of PM2.5, especially transportation. Bangkok has a tropical climate that is influenced by the northeast and the southeast monsoons that result in 3 different seasons: 1) summer from February to April, 2) the rainy season from May to October, and 3) winter from November to January.

2.2 Data collection

Air pollution (PM2.5) data were collected from the 117-meter-high KU Tower (Figure 1), a meteorological and near-surface air quality monitoring tower located at Kasetsart University, Bangkok, Thailand (13°85′45.29 ″N, 100°57′00.12 ″E). The PM2.5 data were collected continuously using a tapered element oscillating microbalance (Thermo Fisher Scientific) positioned 30 meters above ground level. Meteorological data (relative humidity, temperature, air pressure, rainfall, wind speed, and wind direction) were collected at 10, 30, 50, 75, and 110 meters above ground level from January 2016 to December 2020.

2.3 Relationship analysis

For the analysis of the relationships between the PM2.5 concentration and meteorological factors, we collected a dataset containing 31,805 items. Statistical testing was conducted using a confidence level of 0.01. After collecting data, the data will be pre-processing with parameter selection based on the research proposal (Veesommai and Kiyoki, 2018). The analysis consisted of 3 parts: firstly, the data collection and identifying the magnitude and direction from the relationship between PM2.5 concentration and meteorological factors, secondly, identifying significant correlations among variables (Veesommai and Kiyoki, 2019) and lastly, temperature inversion phenomena analysis. The implementation in detail is described below.

2.3.1 Determination of the magnitude and direction from the relationship between PM2.5 concentration and meteorological factors. Pearson correlation coefficient analysis was used.

2.3.2 Determination of relevant meteorological factors affecting the PM2.5 concentration using linear regression analysis and correlation among meteorological factors and PM2.5 concentration change using multiple regression analysis. The change in the PM2.5 concentration meant the analysis could not be restricted to a single factor.

2.3.3 Determination of temperature inversion phenomena

For analysis of the temperature inversion (TI) phenomena, we studied the periods with high PM2.5 concentra-

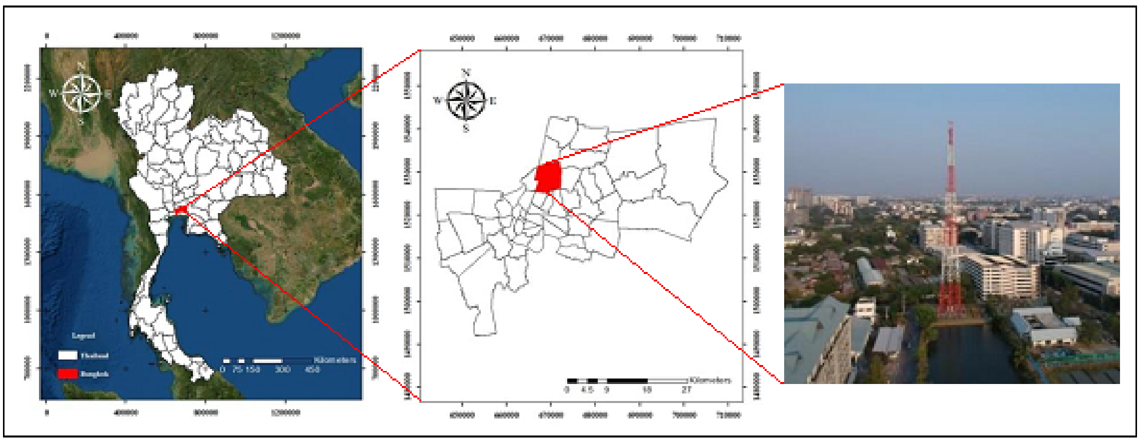

Figure1. Bangkok study area for monitoring of microclimate and air pollutants in Thailand and the data recording station (KU Tower).

tions, namely between October and January and during the day when the PM2.5 concentration exceeded the standard of the Pollution Control Department of not more than 50 μg/m^3. The analysis was based on Equation 1:

$$-(dT/dZ) \qquad (1)$$

where dT is the rate of change of temperature at T1-T0, where T1 is the temperature at altitude n and T0 is the temperature at the surface level and dZ is the changing rate at Z1-Z0, where Z1 is the height at n and Z0 is the height at the surface level, and T0 is the temperature and altitude at the surface level of 10 meters.

3. Results

3.1 Concentration of PM2.5 in Bangkok

The results showed that there were changes in the PM2.5 concentration levels in Bangkok during the 4 years (2016, 2018-2020) at an altitude of 30 meters above ground level where for substantial periods, the PM2.5 concentration exceeded the standard value (50 μg/m^3). The greatest number of hours in excess of the standard was in 2020, followed by 2016, 2019, and 2018, respectively. The highest average hourly concentration was in 2016 (161.94 μg/m^3), followed by 2018 (228.12 μg/m^3), 2019 (292.32 μg/m^3), and 2020 (157.40 μg/m^3), respectively. The PM2.5 level exceeded the standard for 7.13 % of the time (96 days out of 1,345 days), with 54.57% of these periods during the night (7 pm to 7 am) and 45.42% during the day (8 am to 6 pm). The numbers of hours with PM2.5 values greater than 50 μg/m^3 in 2016, 2018, 2019, and 2020 sampled at 30 meters above ground level are shown in Figure 2.

The change in the monthly average of PM2.5 concentration levels showed that PM2.5 tended to decrease from late February to September (summer and the rainy season) and then began to trend up during October to February. During winter, Bangkok is influenced by the northeastern wind and the wind speed, relative humidity, low temperature and high pressure affects the atmospheric movement and results in stagnant air.

A decrease in the dust dispersion rate and the accumulation of PM2.5 causes the PM2.5 level to exceed the standard value. In the current study meteorological factors influenced changes in the concentration of PM2.5 in the atmosphere (Figure 3), which was consistent with the research of Kwanma et al., 2019.

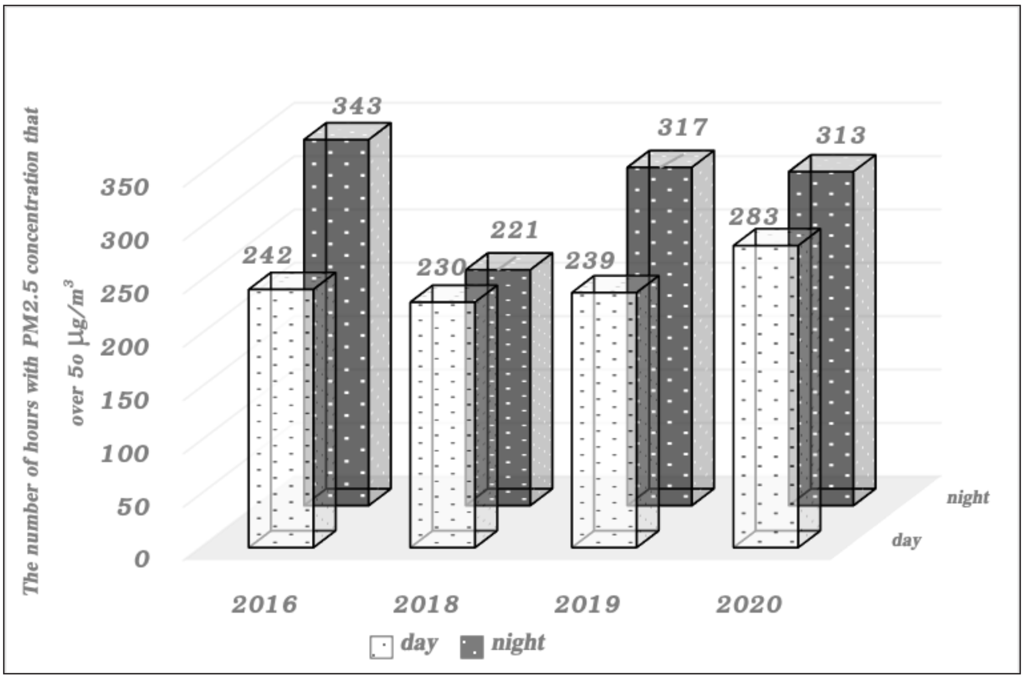

Figure 2. Number of hours for PM2.5 concentration exceeding 50 μg/m3 during 2016, 2018, 2019, and 2020 sampled at 30 meters above ground level.

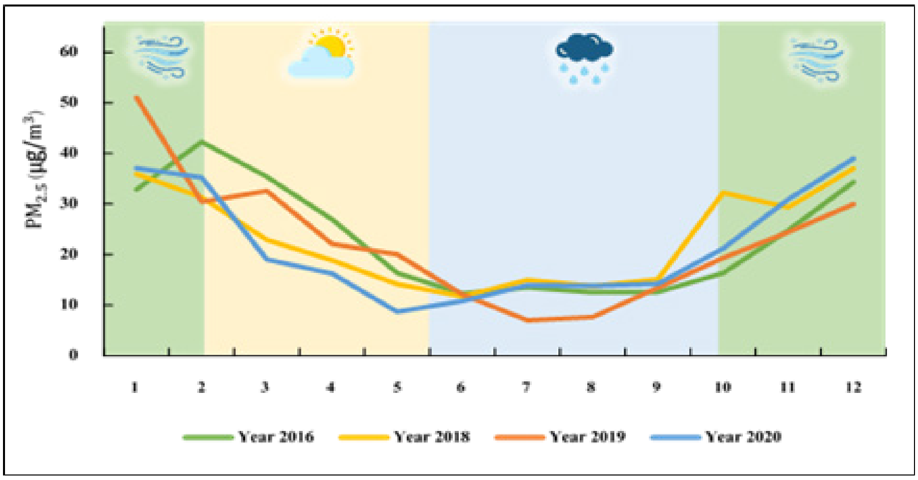

Figure 3. Monthly PM2.5 concentrations during 2016, 2018, 2019, and 2020 at 30 meters above ground level.

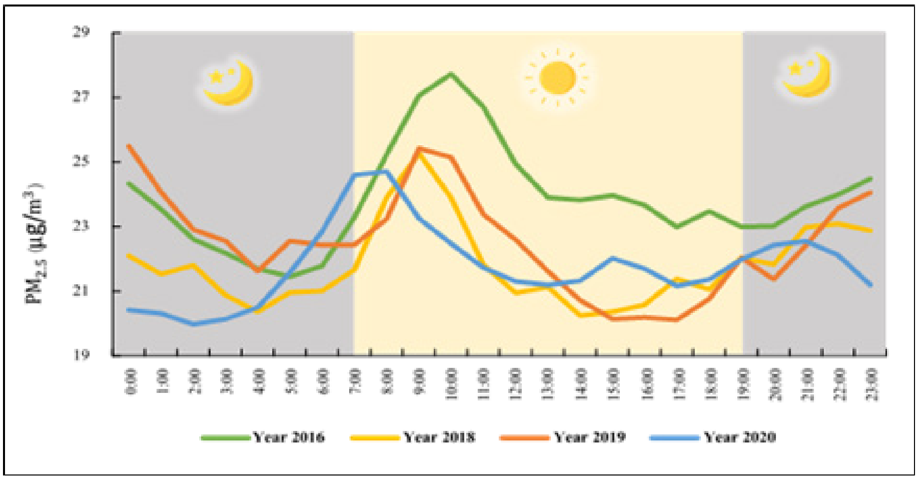

Figure 4. Hourly average PM2.5 concentrations during 2016, 2018, 2019 and 2020 at 30 meters above ground level.

The changes in the hourly average PM2.5 concentration tended to increase during 2 periods—in the morning (6 am to 10 am) and in the afternoon/evening (3 pm to 7 pm). The morning period could have been influenced by various people-related activities, especially traffic and exhaust from diesel engines in vehicles. The hourly average PM2.5 concentrations for 2016, 2018, 2019, and 2020 at 30 meters above ground level are shown in Figure 4.

3.2. Relationship between meteorological factors and PM2.5 concentration

Analysis of the relationship between meteorological factors and PM2.5 concentrations using the Pearson correlation coefficient showed that meteorological factors were significantly inversely correlated with the concentration of PM2.5. Specifically, increases in the relative humidity, wind direction, wind speed, and temperature produced a decreasing trend in PM2.5 concentrations, with correlation coefficients at the 0.01 confidence level of -0.270, -0.127, -0.013, and –0.130, respectively. We found that when the air pressure increased, the PM2.5 concentration increased, with a correlation coefficient at the 0.01 confidence level of 0.084. The Pearson correlation coefficients for climatic factors are shown in Table 1.

The PM2.5 concentration levels decreased when the relative humidity increased but the levels were independent of the accumulated precipitation. In particular, relative humidity in the range 70-100% plays an important role in reducing the concentration of particles (C Lou et al., 2017). When the relative humidity in the atmosphere is high, there may be a higher probability of precipitation as water droplets in the atmosphere attached to dust particles and drop to the ground due to their combined gravitational force.

An increase in the surface temperature can increase the movement of air that can reduce the concentration of dust in an area. In the current study area, the wind direction affected the PM2.5 concentration levels by blowing in dust from other areas or sources, such as from the burning of biomass in agricultural areas in the central region around Bangkok. Lower air velocity area will increase the accumulation and distribution of local dust, so that high pressure and low temperature, which are especially prevalent during the influence of the northeast monsoon result in increased dust concentration in Bangkok.

The linear regression analysis of the relationship between meteorological factors and PM2.5 dust concentrations showed that the relative humidity had the highest correlation with the concentration of PM2.5 (42.3%), followed by wind direction (40.3%), temperature(21.4%), air pressure (1.6%), and wind speed (0.07%), respectively. The results from the linear regression are shown in Table 2.

Table 1. Pearson correlation coefficient analysis of climatic factors.

Correlations

		BLD_PM2.5	H10M_BP	H30M_WS	H30M_WD	H30M_TEMP	H30M_RH
BLD_PM2.5	Pearson Correlation	1	.083**	-.013	-.127**	-.130**	-.270**
	Sig. (2-tailed)		<.001	.272	<.001	<.001	<.001
	N	7595	7595	7595	7595	7595	7595
H10M_BP	Pearson Correlation	.083**	1	-.179**	-.026*	-.021	-.072**
	Sig. (2-tailed)	<.001		<.001	.025	.063	<.001
	N	7595	7595	7595	7595	7595	7595
H30M_WS	Pearson Correlation	-.013	-.179**	1	-.280**	.029*	.022
	Sig. (2-tailed)	.272	<.001		<.001	.012	.056
	N	7595	7595	7595	7595	7595	7595
H30M_WD	Pearson Correlation	-.127**	-.026*	-.280**	1	.194**	-.059**
	Sig. (2-tailed)	<.001	.025	<.001		<.001	<.001
	N	7595	7595	7595	7595	7595	7595
H30M_TEMP	Pearson Correlation	-.130**	-.021	.029*	.194**	1	-.507**
	Sig. (2-tailed)	<.001	.063	.012	<.001		.000
	N	7595	7595	7595	7595	7595	7595
H30M_RH	Pearson Correlation	-.270**	-.072**	.022	-.059**	-.507**	1
	Sig. (2-tailed)	<.001	<.001	.056	<.001	.000	
	N	7595	7595	7595	7595	7595	7595

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2 Simple linear regression model for predicting PM2.5

Meteorological factor	Simple linear regression model	r	R^2	p-Value	n
Air pressure (A)	PM2.5= 1.11 + 0.02A	0.126	0.016	0.351	57
Wind speed (Ws)	PM2.5= 20.65 + 1.15Ws	0.084	0.007	0.536	57
Wind direction (Wd)	PM2.5= 53.57 – 0.173Wd	0.635	0.403	0.000	57
Temperature (T)	PM2.5= 140.29 – 4.04T	0.450	0.202	0.000	57
Relative humidity (R)	PM2.5= 89.64 – 0.98R	0.651	0.423	0.000	57

The results from the multiple linear regression analysis between meteorological factors and the PM2.5 concentration using the stepwise technique showed that the humidity, wind direction, temperature, and rainfall were significantly inversely correlated with the concentration of PM2.5 and could explain 64.2% of the variation in PM2.5. The relationship among meteorological factors and the PM2.5 concentration is described in Equation 2:

$$PM2.5 = 144.459 - 0.498RH - 0.086WD - 2.423Temp \quad (2)$$

$$(R^2 = 0.642)$$

3.3. Results of temperature inversion phenomena with PM2.5

Considering the temperature change by altitude (30, 50, 75, and 110 meters) and the change in temperature at 3 elevation levels (50, 75 and 110 meters), the TI phenomena occurred at 4 altitudes. In 2020, there was the highest occurrence of TI phenomena (233 hours in 57 days), which occurred at 4 altitudes for 155 hours and at 3 altitudes for 78 hours. In 2019, the TI phenomena (166 hours in 37 days) occurred at 4 altitudes (102 hours) and at 3 altitudes (62 hours). In 2018, the TI phenomena (160 hours in 50 days) occurred at 4 altitudes (93 hours) and 3 altitudes (67 hours) and in 2016, TI phenomena (204 hours in 52 days) occurred at 4 altitudes (162 hours) and at 3 altitudes (42 hours). The number of hours of TI during 2016, 2018, 2019, and 2020 are shown in Figure 5.

The TI phenomenon results from natural convection, which directly affects the occurrence of precipitation and the amount of moisture in the atmosphere. It was caused when there was dust or polluted air in the atmosphere in Bangkok and also causes the accumulation of dust that forms at the surface level as it cannot float into the outer atmosphere. Especially in winter, when the wind is calm and the air and urban surfaces are heated by the accumulation of sunlight, following sunset, the surface cools quickly. On the other hand, slow cooling air is affected by the characteristics of the city's surface, where a heat dome effect may arise covering the area and causing the TI phenomenon. During the night, the thermal layer blocks the dust floating. Therefore, it was often found that the dust in the city decreased in the afternoon and levels soared in the middle of the night.

4. Discussion

From the study of the relationship between meteorological factors and PM2.5 concentration: relative humidity, wind direction, rainfall, wind speed, air pressure, and temperature, there was a statistically significant relationship that could represent 64.2 % of the

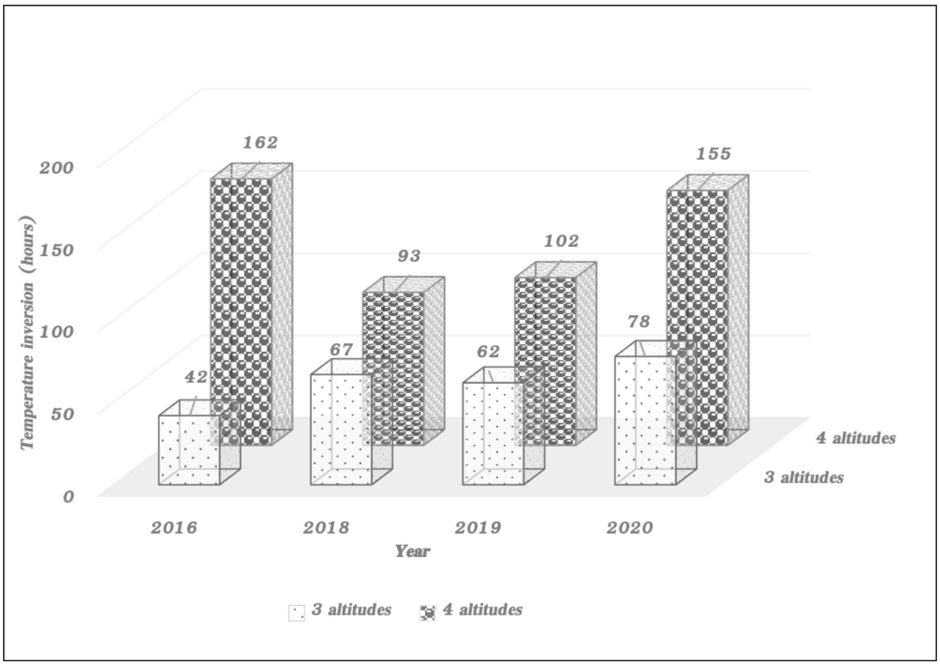

Figure 5. Number of hours of temperature inversion during 2016, 2018, 2019, and 2020.

variation in PM2.5. The relative humidity, wind direction, rainfall, wind speed, and temperature were inversely correlated with the PM2.5 concentration. The variation in PM2.5 concentration with air pressure was consistent with the study of Kwanma et al. (2019). The PM2.5 concentration increased with high air pressure while the relative humidity, air temperature, wind speed, and low rainfall decreased. The maximum concentration of PM2.5 was in winter (November to February), which was related to the wind direction as this is a crucial factor blowing dust from other areas into the study area, which was consistent with the study by Chakrit and Duangnapha (2018) that reported the daytime PM10 concentration exceeded the standard due to winds blowing dust from the south to the west into the city of Chiang Mai in northern Thailand.

The maximum concentration of PM2.5 in 2020 was due to cold air masses from China (northeast monsoon) spreading over the area, making the weather unstable. In addition, 54.57% of excess PM2.5 concentration occurred during the night (7 pm to 7 am) due to the local accumulation of PM2.5 as a result of stable air movement and low temperature and low wind speed conditions in the study area. Dust provides a medium to increase humidity and water vapor in the atmosphere because during the night, the atmosphere cools and humidity increases; therefore, the amount of dust particles increases. Some of this nocturnal increased in dust will be removed due to sunlight during the day. During the day, the concentration of PM2.5 tended to increase during 2 periods—during the morning period (6 am to 10 am) and during the afternoon/evening (3 pm to 7 pm). In addition, during the day, many vehicles are used in rush hours for transportation, and these are a major source of PM2.5, which was consistent with the study of Patcharasak (2019) that reported higher dust levels in the morning than in the evening, due to traffic.

There was an increasing trend in PM2.5 during October-February (winter season) in Bangkok, due to the influence of the north-east monsoon and the movement of high pressure into the area that affected stability of the air and resulted in PM2.5 accumulation in the study area.

TI phenomena occur when the air temperature does not decrease with altitude. TI results when there is cooler air in the upper and lower levels and there is no opportunity for ventilation in the area, with a resultant impact on the PM2.5 concentration distribution, which was consistent with the study of Zang et al. (2017). The number of hours for TI phenomena greatly affected the PM2.5 concentration accumulation in the study area over a longer time. In 2020, TI phenomena occurred for long periods of several hours, which was consistent with the study of Thuy et al. (2019) that found TI phenomenon occurred for a long time in winter when the concentration of pollutants in the surrounding air tended to be higher than in normal times and often occurred at altitudes from 300 to 1,800 meters in winter and from 100 to 600 meters in summer. The current study results showed the same trend as reported by Xu et al. (2019) who found that the first occurrence of upper-level temperature inversion occurred at 800 meters and the second appeared at about 90 meters from the surface. An important factor is the characteristics of the area or of the land use and activities taking place in the area. Thus, in areas consisting of urban areas, buildings, and concrete, there will be more TI phenomena more than in rural areas. Sam et al. (2009) reported that the influence of soil cover or the surface of an area is an important factor in contributing to the occurrence of TI phenomena.

5. Conclusion

The study found that PM2.5 concentrations exceeding the standard of 50 $\mu g/m^3$ tended to increase during rush hours and that meteorological factors such as relative humidity, wind direction, precipitation, air speed, air pressure, and temperature affected the concentration and distribution of PM2.5, especially the relative humidity. The relationship developed among the meteorological factors accounted for 64.2% of the PM2.5 concentration change, as shown in Equation 2:

$$PM2.5 = 144.459 - 0.498RH - 0.086WD - 2.423Temp \quad (2)$$

The study of TI showed that the longer the TI continued, the greater its effect on increasing the concentration and dispersion of PM2.5 particles. The greatest TI occurrences were during 2020, followed by 2016, 2019, and 2018, respectively. The increased incidence and longer durations of TI were influenced by the surface characteristics of urban areas in Bangkok, which consisted mainly of concrete, buildings, and roads that are all low thermal conductivity materials, and all have high heat radiation. Therefore, the temperature rapidly increased during the day and greatly decreased during the night. Furthermore, the decreasing area of green vegetation cover also can affect temperature variation during the day and night.

In conclusion, the results of the current study quantified the relationship between meteorological factors and the PM2.5 concentration. This can be utilized to help solve problem associated with unacceptable levels of PM2.5.

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