The influence of meteorology on ambient PM2.5 and PM10 concentration in Chiang Mai

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Abstract. A concentration of particulate matter (PM), i.e. PM10 and PM2.5, peaks annually in March from 2015 to 2018, exceeding both Thailand emission (24-hour averaged 120 µg/m3 for PM10 and 50 µg/m3 for PM2.5) and World Health Organization (WHO) standards. This study will consider relationship between the PM concentrations and meteorological data of Chiang Mai in 2018 affecting the highest PM near surface. The hourly PM10 and PM2.5 concentrations in Chiang Mai town reach the maximum values on 30 March 2018 by two stations 35T (Chiang Mai city Hall) and 36T (the Yupparaj Wittayalai School). The former is 155.22 µg/m3 at 35T and the latter is 117.73 µg/m3 at 36T, superior to the Thailand standard. When both PM concentrations are over the standard, slightly stable atmosphere are occurred as indicated by E-class stability plot. Furthermore, an atmospheric inversion near surface appears from ground level to approximately 660 mb as shown in Skew-T diagram so air pollutants in Chiang Mai are trapped underneath 50 meters height of planetary boundary layer. Persistent slightly stable and neutral atmosphere (E and D class, respectively) approximately 24 hours in Chiang Mai also encourages surplus PM10 and PM2.5 from 28 to 30 March 2018 in accordance with low speed western and south western winds (1 m/s to less than 4 m/s).

1. Introduction

People activities, such as private and public transportation, biomass burning, forest fire, open burning etc., are related with air pollution and source emissions. Two of those can be a particulate matter with diameter less than 10 µm and less than 2.5 µm as known as PM10 and PM2.5 respectively. The Thailand Pollution Control Department (PCD) keeps monitoring PM10 and PM2.5 concentration for many locations in Thailand including Chiang Mai (CM). CM is at latitude 18.7N and 98.74E located in valley of Chiang Mai-Lamphun Basin, and CM urban is near Suthep Mountain. Due to its topographic terrain, a surface temperature inversion is effect to air quality near ground level [7], [11], [13], [14], [17], [18]. Surface inversions are responsible for trapping the pollutants produced by vehicles, fires and industrial activities [11] especially during the winter when the inversion is substantially enhanced. It traps a cool air layer at the surface topped with warm air layer and decreases vertical mixing [18]. The strength and duration of the inversion will control Air Quality Index (AQI) levels near the ground [11]. Nevertheless, CM surface temperature inversion can occur in hot season, CM has million local people and tourists visit annually. Their activities, such as biomass burning, wastes burning and traffic, can generate pollutants especially particulate matter. The results show that CM got the highest annual average PM2.5
from January to July 2016 and is higher than WHO standard. The average maximum monthly is 144 
µg/m³. In 2014 and 2015, CM reach the average annual PM2.5 with 34 µg/m³ and maximum monthly 
are 188 and 266 µg/m³, respectively [6]. Thailand ambient air emission standard for PM2.5 and PM10 
respectively are 24-hour averaged 50 µg/m³ and 120 µg/m³ respectively, while WHO standard for those 
are 24-hour averaged 25 µg/m³ and 50 µg/m³ [19]. The meteorological data are also the very important 
parameters effect to particle concentration in ambient [8] because they can describe the air conditions 
when the high concentration of dust is shown. At the monitoring stations, they have to show ground 
temperature, relative humidity, air pressures, wind speed and direction [2], [16] etc., together the PM2.5 
and PM10 concentrations [5]. Correlation between PM2.5 and PM10, also meteorology, has to be 
described [1], [3], [20]. Boundary layer depth is the one effect to air pollution that about 100 m [4]. The 
vertical mixing coefficient (m²/sec - mixing length times velocity) is a measure of the turbulent mixing 
within the boundary layer used by HYPLIT transport and dispersion model to calculate the vertical 
movement of pollutants [9]. The amount of atmospheric turbulence present into six stability classes A, 
B, C, D, E and F when class A being the most unstable, and class F the most stable [10]. This study aims 
1) to study the PMs concentration of CM to explore when surplus PMs (compared with standard) occur 
from 2015 to 2018, and to understand PMs concentration differences between urban air and sub-urban 
air, 2) to correlate PM2.5 concentration on PM10 concentration for CM in order to assess 
interchangeably prediction for PMs in 2018, and to find the relationship between relative humidity and 
temperature during the maximum PMs concentration, and 3) to analyze meteorological condition 
associated with PMs concentration.

2. Materials and Methods

2.1. Monitoring sites

PCD operates two stationary monitoring sites in CM. The 35T is the sub-urban station at Chiang Mai 
city Hall on the North of a CM town, while the 36T is at the Yupparaj Wittayalai School located at the 
center of CM town. Both stations report an hourly ambient PM2.5 and PM10 round the clock, and 
automatically calculates 24-hour average data (9.00am to 8.00am the next day). Meteorological data 
such as wind speed, wind direction, relative humidity, precipitation etc., are shown in the hourly average 
on the PCD website [12], [15].

2.2. Analysis Methods

In this study, we adopted both daily 24-hour average PMs concentration, and hourly PMs concentration 
recorded from two stations. The inferential statistical ANOVAs to distinguish the daily data of the same 
period (2015-2018). Then, those PMs concentration are selected to find the certain period in this work 
and assess the correlations of each parameters by the scatter plots with Excel. The meteorological 
conditions from the Global Forecast System model (0.5x0.5 degree, 0-84h, 3hrly, Global pressure-sigma 
hybrid) in Chiang Mai are analyzed. Thus, the air stability class (atmospheric turbulence), Skew-T 
diagram for vertical atmospheric profile, and wind roses for 10m are created via Real-time 
Environmental Applications and Display sYstem (READY) Program from the NOAA website [10].

2.3. Statistical Analysis data from 2015 to April 2017

The descriptive statistics background of PM10 concentration from 2015 to 2017 was shown in Table 1. 
The PM10 maximum concentration at 35T station was 292, 171 and 153 µg/m³ from 2015 to 2017 
respectively, while the PM10 maximum concentration at 36T station was 299, 192 and 125 µg/m³ from 
2015 to 2017 respectively. All of those exceeded Thailand standard criteria (120 µg/m³). PM10 
concentration on both stations had negative trend towards restricted regulation on open burning in 2017, 
and the 36T had higher PM10 concentration than 35T due to biomass burning, traffic and business 
activities. Furthermore, the daily 24hr average PM10 concentration at 35T station also decreased from 
2015 to 2017, but the daily 24hr average PM10 concentration at 36T in 2016 reached 89.27 µg/m³ with
σ = 33.530 μg/m³. However, the PM10 concentrations mean between 2015 and 2017 for both 35T and 36T station significantly differs to each other at 0.05 level regarding to ANOVA test. The PM10 concentration during study period each year can be discussed separately.

| Table 1. descriptive statistics background of PM10 concentration from 2015 to 2017 |
|---------------------------------------------------------------|
| Statistics | 35T 2015 | 35T 2016 | 35T 2017 | 36T 2015 | 36T 2016 | 36T 2017 |
| N           | 132     | 132     | 132     | 127     | 127     | 127     |
| Mean        | 75.02   | 71.88   | 63.36   | 80.27   | 89.27   | 55.79   |
| Std. deviation | 46.54   | 31.61   | 26.61   | 49.60   | 33.53   | 20.99   |
| Minimum     | 6       | 4       | 10      | 14      | 10      | 9       |
| Maximum     | 292     | 171     | 153     | 299     | 192     | 125     |

3. Results and Discussions

3.1. Particulate Matter Concentration (PM)
PM concentration has been observed since 2015 to the beginning of April in 2018 (Figure S1. and S2.). They show the PM2.5 and PM10 are highest in March each year. The minimum ones are in rainy season (from May to September) and start increasing again in October to peak in March. According to this background, this study considers only the PM2.5 and PM10 data from 1 January to 6 April 2018 (Figure 1. and 2.). Then, specific meteorological data for the highest concentration in this period are discussed on 28-30 March 2018 (Figure 3. and 4.).

3.1.1. Daily PM2.5 and PM10 from 1 January 18 to 6 April 18
PM2.5 and PM10 are continuously increasing daily (Figure 1. and 2.). The minimum and maximum 24hr-averaged concentration are shown in 2, 13 January and 30 March 2018, respectively (Figure 1. and 2.). Two comparisons between observed 35T, 36T data with Thailand standard and with WHO guidelines are described. Being compared with Thailand standard, PM2.5 is 50% (36T) - 62.5% (35T) in February, 93.5% (35T) – 90.3% (36T) in March, and 33% (35T, 36T) in April over Thailand standard (Figure S4.), but PM2.5 is under standard only in January. For comparison with WHO guidelines, PM2.5 from 35T and 36T are over standard around 55-87% in January, and 100% from February to April (Figure S4.). For daily PM10 with Thailand standard, no data is over standard on January, February, and April. Only in March, 29% (35T) and 6% (36T) are exceeded standard (Figure S3.). When comparison with WHO guidelines, from January to April, 35T and 36T show dramatically increase from 35.5% to 100% and from 9.7% to 100% are over standard, respectively (Figure S3.).
3.1.2 Hourly PM10 and PM2.5 on 28-31 March 2018 start 0.00 am to 23.00 pm each

Although the maximum daily PM2.5 and PM10 are shown on 30 March (Figure 1. and 2.), the hourly PM10 is maximum (182.62 µg/m³) on lately morning (11.00 am) on 30 March (35T) (Figure 3.) and PM2.5 peaks (142.83 µg/m³) at night time on 29 March (36T) (Figure 4.). PM2.5 and PM10 on 29-30 March are exceed Thailand standard and WHO guidelines.
3.1.3 Correlation of hourly PM2.5 and PM10, also hourly T and Rh% from 1 January 2018 to 6 April 2018

Correlation between hourly PM10 and PM2.5 show in Figure 5, for 35T and 36T station. Station 35T show the linear equation with R= 0.90 and 36T with R= 0.88 calculated from N = 2,194 and 2,081, respectively. These equations from 35T and 36T, showed the characteristic of PM2.5 and PM10 from 1 January 2018 to 6 April 2018. When you observed PM2.5 on these stations, they can classify PM10 from equations directly. The more PM2.5 concentration has increased, the more PM10 concentration has increased for both stations. Moreover, correlation between hourly T and Rh% shows great response (Figure 6), linear equation expresses negative slope with R=0.86 for 35T and with R=0.84 for 36T. They are plotted by N = 2,153 and N = 2,163, respectively. The more temperature goes up, the less Rh% goes down. The T and Rh% are linked to dew point temperature (Td) by equation Rh% ~ 100 − 5(T−Td). Figure 5 shows strong correlation of PM2.5 and PM10, also T and Rh% for this study. They can imply that dry season from January (late cold season) to April (hot season) in CM, PM2.5 and PM10 are continuously high with increasing temperature and decreasing Rh%.

3.2 Meteorological data

3.2.1 Skew-T plot on 28-30 March 2018 at initial time as input data at 00 UTC

Skew-T diagram explains vertical ambient air profile from the ground up to the upper atmosphere as seen in Figure 7. The red solid line refers to environmental lapse rate, while the green solid line refers to dew point temperature. CM during March 28-30, 2018 has shallow inversion at ground level and thick inversion around upper 660mb all day and night. Generally, temperature inversion dissipates in the afternoon when the atmosphere is being heated, furthermore, surface temperature inversion occurs in winter time for upper latitude countries. CM town can encounter this especially during seasonal transition into hot season whereas vertical high pressure still be active. The more slope of environmental lapse rate leans to the right, the stronger inversion is. Hence, persistent inversions will prevent air rising up, and cause higher PM2.5 and PM10 concentration on ground level.
Figure 7. Six hourly Skew-T plot on 28-30 March 2018 at initial time at 00UTC as input data
3.2.2 Wind rose and stability class from 28-31 March 2018

Boundary layer depth (BLD, red solid line) in CM town from 28 to 31 March 2018 is around 2,800 m during daytime and around 50-100 meters during night time as shown in Figure 8. The BLD is related with stability of air, so CM daytime show unstable air with B and C class. Besides BLD, the scaled vertical mixing coefficient (blue solid line) during day time decreases day by day and reach the minimum on March 30, 2018. This point out that the vertical mixing was substantially suppressed during the day time. For night time to early morning, stability change to stable and neutral class (E and D). The BLD level and stability class are also effect to PM concentration. The lower BLD level, the more PM concentration at ground in night time (Figure 8). Calm wind (less than 4 m/s) on 28 March to 31 March also effect to high PM concentration due to less turbulent encouragement. Western, South western, and North western wind are effect to CM on 28-31 March (Figure 9).

4. Conclusions and recommendations

The maximum daily PM2.5 and PM10 are shown in 30 March 2018 both 35T (110.9 and 155.22 µg/m$^3$) and 36T (117.73 and 133.35 µg/m$^3$), respectively. The minimum daily PM2.5 and PM0 are shown in January 2018 both 35T (20.87 and 32.71 µg/m$^3$) and 36T (12.44 and 22.28 µg/m$^3$), respectively. The 3-month average of PM2.5 and PM10 are 51.53 and 78.67 µg/m$^3$ for 35T, also 49.29 and 63.22 µg/m$^3$ for 36T, respectively. From different monitoring stations, they are implied that sources of PM10 at 35T are from biomass, forest fires and open burning when 36T are from the mix sources such as open burning, traffic and human activities. Because daily PM10 concentration of 35T significantly decreased from 2015 to 2017 according to Thai regulation, the ones at 36T are fluctuation with $\sigma = 33.530$ µg/m$^3$ in 2016. Hourly PM2.5 and PM10 starts to exceed Thailand standard and continuously increase from 7.00 am on 29 March to 2.00 am on 31 March 2018. The maximum PM2.5 is 142.83 µg/m$^3$ at 36T and PM10 is 182.60 µg/m$^3$ at 35T. Both of peaks are occurred on 29 and 30 March 2018 at 7.00 pm and 11.00 am, respectively. Nearly 100% of data from February to March 2018, both PM2.5 and PM10 by 35T and 36T in CM are over WHO guidelines. More than 90% in March 2018, PM data are over Thailand ambient air standard. Correlation between PM10 and PM2.5 are strong with $R = 0.90$ at 35T and 0.88 at
36T by linear positive slope. Also correlation of T and Rh% are strong with R= 0.86 at 35T and 0.84 at 36T. The most meteorological data that affect to CM town are the persistent atmospheric inversion which is active all day and night. It suppresses vertical air motion during the day time, and narrow down the BLD up to 50 meter height during the night. It also causes air stability change to stable and neutral class (E and D). Another reinforcing factor is calm wind at 1 m/s to less than 4 m/s which discourages air turbulence. The wind directions are from western, south western, and north western which can be related to transboundary pollution. Further investigation might be applied such as back trajectory to give supportive information. On March 30th, 35T-maximum PM10 concentration (182.62 ug/m³) exceeded Thailand standard with Rh% (41.95) and temperature (32.07 °C).

Long plan and action period of restricted regulation on open burning from the Thai Government in November 2016 to 20 April 2017, it makes the less PM in CM in comparison with data in 2015. However, in 2018, the Thai regulation just started lately on 1 March to 20 April 2018, the PM has been continuously increasing from January to end of March with exceed Thailand standard. Distribution and communication data to local community, social network and Department of Tourism in CM are necessary and for sharing information to people who have to affect with high concentration of PM2.5. CM could have the warning system in real time PM2.5 monitoring and link to network and community. Finally Thailand could change ambient PM2.5 standard from 50 to 25 µg/m³ as WHO standard. The lower ambient emission standard, the better health for Thai people and tourisms.

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Supplementary data

Figure S1. Daily PM2.5 in Chiang Mai from 2015 to 2018

Figure S2. Daily PM10 in Chiang Mai from January 2015 to April 2018
**Figure S3.** Number of daily PM10 data that exceed Thailand standard and WHO guideline in 2018

**Figure S4.** Number of daily PM2.5 data that exceed Thailand standard and WHO guideline in 2018