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Research Article

Spatial and Temporal Variations of Atmospheric PM_{10} and Air Pollutants Concentration in Upper Northern Thailand During 2006–2016

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Abstract
Hourly data of PM_{10} mass concentrations obtained from 13 air pollutants monitoring stations in 8 provinces of the Northern Thailand by Pollution Control Department (PCD) and hotspot data collected from NASA's Earth Observatory website during January 2006 – December 2016 were analyzed. The annual mean, episode mean and non-episode mean of PM_{10} concentration in the Northern Thailand were 45.3 ± 43.8, 79.2 ± 56.8 and 28.7 ± 21.0 μg/m^3, respectively. The hotspot and PM_{10} levels showed high level in biomass burning season and the highest in March, the same trend pattern was observed every year. PM_{10} concentration during smoke episode was higher than those in non-smoke episode with statistic significant ($p < 0.05$). Cleared diurnal variations of PM_{10} level showed a bimodal pattern with peaks during 8.00–10.00 am as well as 7.00–9.00 pm in both episodes. The level of CO, SO_2 and nitrogen oxides represented similar pattern variations. It is because these periods are rush hour duration with an increased traffic volume in every area of monitoring stations. The association between particulate matter and air pollutants showed strong positive relationship ($p < 0.01$). The results showed that both the vehicle emissions and biomass burning were major sources of atmospheric particle. Hazard index (HI) during long term exposure exceeded the acceptable level of non-carcinogenic adverse health risk (HI > 1).

Keywords: Air pollution, PM_{10}, Biomass burning, Hazard index, Northern Thailand

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1 Introduction

Air pollution issue has become the world's biggest serious environmental problem. It refers to the growing population and technology which sharply enlarge the contamination of harmful physical and biological materials in the atmosphere [1], [2]. The consumption of fossil fuel has increased significantly with the industrial development all over the world. The vehicles which consume fossil fuel have also been developed as one of effective transport facilities. Such industries brought in quality of life to human, while the consumption of large amount of fossil fuel has caused several serious atmospheric pollutions [3].

Furthermore, forest fires smoke emissions and prescribed burns are responsible for provisional violent episodes of air pollution. In the developing countries, biomass smoke is a severe cause of indoor air pollution because biomass fuels are the main source of energy for cooking and heating, and the wood smoke cause serious indoor air pollution [4]. Southeast and East Asia are the regions where the main source of smoke particulate matters were obtained from biofuel and biomass burning [5]. Biomass burning emissions are one of the major sources of air pollution not only in Northern Thailand but also in the neighbouring countries such as Myanmar, Laos, Vietnam and Cambodia [6], [7]. In the North of Thailand occurred the first crisis of the air pollution problem in 2007 [8]. Moreover, the forests in the North of Thailand are mostly tropical deciduous, which are dry dipterocarp and mixed deciduous forest. During dry season, January to April, the forest shed leaves [9]. Dry leaves are the fuel source of forest fire every year which affected many areas of the northern part of Thailand where particulate matter with aerodynamic diameters less than 10 microns (PM_{10}) concentration is higher than safety standards and highest number of days that PM_{10} exceeded standard. Biomass burning is considered to be the potential major source of toxic releasing into the ambient air and the increase of the suspended micro-particulate matters, which comprise of black elemental carbon (soot particles), organic and inorganic matter [10], [11] and gaseous compounds including of carbon monoxide (CO), carbon dioxide (CO_2), Oxides of nitrogen (NOx), methane (CH_4) and ammonia (NH_3) [12]. The composition of smoke depends on type of biomass, humidity, temperature, winds and various weather conditions [13]. The major oxidant responsible for photochemical smog are CO, ozone (O_3), nitrogen oxides (NO, NO_2), sulphur dioxide (SO_2) and sulphuric acid (H_2SO_4), suspended particulate matter (SPM), and volatile organic compounds (VOCs). The reactions between their pollutants and sunlight are the cause of photochemical smog, which can be extremely harmful, leading to irritations of the respiratory tract and eyes [14].

Air pollution is extremely linked with health hazard and deaths by both indoor and outdoor exposure of pollutants. Human exposure of air pollutants from indoor or outdoor environments can be by inhalation, ingestion of food and skin contact [15]. Major effects on human health from PM_{10} exposure include breathing and respiratory system problems, lung tissue damage, cancer and premature death. The elderly, children and people who chronic with lung disease, influenza or asthma are especially sensitive to the effects of particulate matter [16]. Particulate matters (PM_{10}) from forest fire have multiple impacts on locally and public health, because smoke can be transported several thousands of kilometers downwind from the combustion source [17], [18]. Numerous epidemiologic studies have shown an association between exposure to PM_{10} and total mortality and an increase cardiopulmonary mortality was associated with long-term exposure to PM air pollution in USA [19]. Moreover, the air pollution in upper Northern Thailand also affect both human health and environmental health, especially the global climate change in the long time. In addition, the government needs to spend a lot of unnecessary budget to manage forest fires and treating the patients in every year. The objectives of this research are to determine the variation of PM_{10} concentration during episode and non-episode of smoke, to investigate the association of PM_{10} concentration, gaseous pollutants and meteorological and to assess the impact of pollutants to the local people health risk in the upper northern of Thailand.

2 Data and Methodology

2.1 *Study sites and data used in the study*

The data in this study was conducted during 11-y period (January 2006–May 2016). The hourly, daily and monthly PM_{10} concentration and gaseous pollutants data from January 2006 to December 2016 were

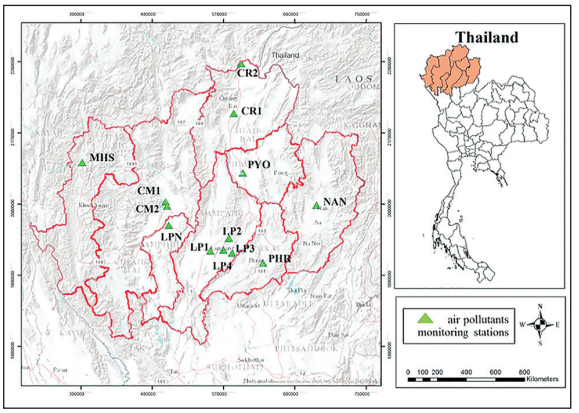


Figure 1: Map of the 13 air pollutants monitoring stations in the upper Northern Thailand.

obtained from the Pollution Control Department (PCD), Ministry of Natural resources and Environment, Thailand. The detail and location of 13 air pollutants monitoring stations in the upper northern part of Thailand show in Figure 1 and Table 1. Forest fire and burnt area data were supported by the Forest Fire Control Division National Park, Wildlife and Plant Conservation Department and the Protected Area Regional Office 16 Chiang Mai Branch. Additionally, the active fire data or hotspots in the upper Northern Thailand were extracted daily from NASA's Earth Observatory website (https://earthdata.nasa.gov) by the Moderate Resolution Imaging Spectroradiometer (MODIS). The MODIS is instrument from operating on board both Terra (EOS AM) and Aqua (EOS PM) satellites.

Table 1: Location and station code of 13 air pollutants monitoring stations

Started	Province	Station Code	Latitude	Longitude
Jan 2006	Chiang Mai	CM1	18.8406	98.9697
Jan 2006	Chiang Mai	CM2	18.7911	98.9900
Jan 2006	Lampang	LP2	18.4197	99.7273
Jan 2006	Lampang	LP3	18.2507	99.7640
Jan 2006	Lampang	LP4	18.2827	99.6599
Sep 2008	Mae Hong Son	MHS	19.3047	97.9710
Sep 2008	Chiang Rai	CR1	19.9092	99.8234
Jun 2009	Lamphun	LPN	18.5674	99.0080
Jun 2009	Nan	NAN	18.7889	100.7764
May 2010	Phare	PHR	18.1289	100.1623
Jun 2010	Phayao	PYO	19.1639	99.9027
Jul 2011	Chiang Rai	CR2	20.4272	99.8837
Jan 2013	Lampang	LP1	18.2783	99.5064

2.2 *Data analysis*

This study was divided into three parts. The first part of the study was to investigate the variation of PM_{10} in upper northern of Thailand and the relationship between hotspots and forest fire. The smoke episode is during January to April and non-episode is during May to December. These periods grouped by the data recording of PM_{10} during 11 years that shown the number of day exceeding the safety standards (120 µg/m^3) of Thailand in January till April. Hourly, daily and monthly plots of PM_{10} concentrations were obtained to investigate the variation during episode and non-episode of smoke. In the second part of the study, the relationship between PM_{10} concentration, gaseous pollutants and meteorological in the upper northern part of Thailand were analyzed with Pearson correlation analysis method. Gaseous pollutants including CO, NO, NO_2, NO_x, SO_2 and O_3 were measured at the same period as the PM_{10}. The last part of this study, the impact of particulate matter to health risk in the upper northern part of Thailand was evaluated by the hazard quotient (HQ) and the hazard index (HI) [20]–[22]. The hourly, daily and monthly PM_{10} concentration data of 13 stations in 8 provinces from PCD and hotspots data during January 2006 to December 2016 were analyzed.

$$EC = (CA \times ET \times EF \times ED) / AT \quad (1)$$

$$HQ = EC / RfC \quad (2)$$

Where: EC - exposure concentration (µg/m^3), CA - contaminant concentration in air (µg/m^3), ET – exposure time (24 hours/day), EF - exposure frequency (350 day/year), ED - exposure duration (30 years), AT – averaging time (ED in year × 365 days/year × 24 hours/day), RfC - inhalation reference concentration as the acceptable safety level for chronic non-carcinogenic and developmental effects; PM_{10} = 50 µg/m^3 , CO = 50 ppm and O_3 = 0.1 ppm [23].

3 Results and Discussion

3.1 *Wildfire and hotspot in upper Northern Thailand*

Data of wildfire was recorded during the period of January and May in 2006–2016. The historical trend in forest fire in northern part of Thailand shows that

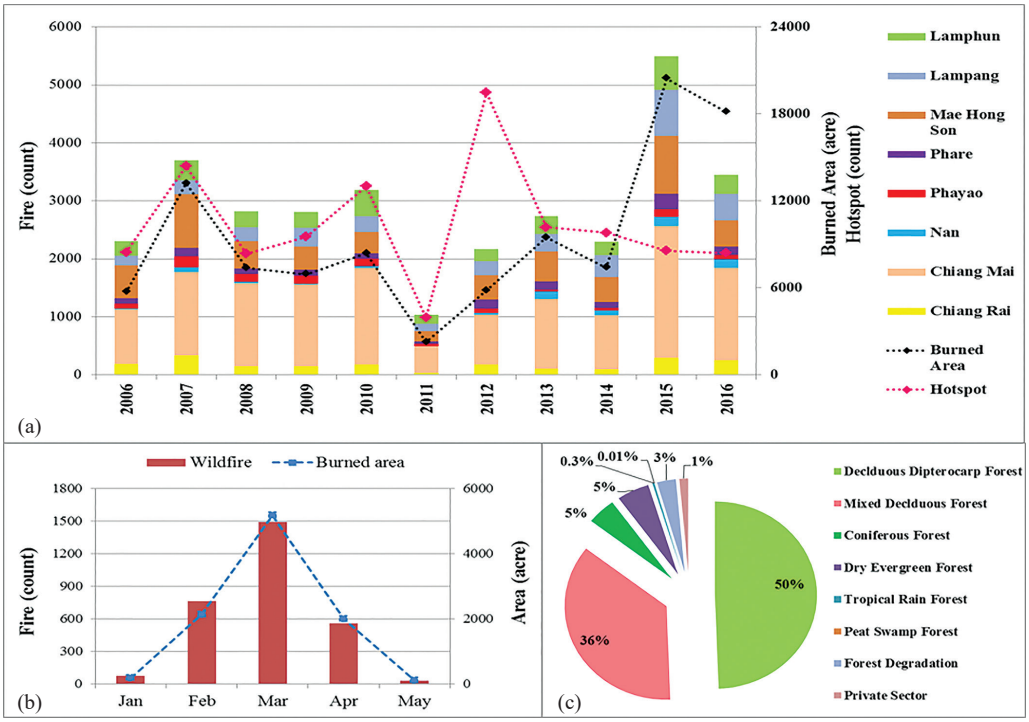


Figure 2: Wildfire frequency and the burned area in yearly (a), monthly (b) and the type of burned area (c) in the upper north of Thailand.

event of forest fire was highest in 2015 (5,497 time) and number of forest fire was highest in March as show in Figure 2(a) and (b), respectively. The total number of fires during 11 years was 31,994 and the total area burnt was 105,046.3 acre. The highest average area burnt per fire event was at Nan province with 5.1 acre/year, while Chiang Mai was occurred the highest mean of wildfire count and burned area. The Figure 2(c) demonstrates the types of burned areas in the north of Thailand. The results showed that the most burned areas were deciduous dipterocarp forests (50%) and mixed deciduous forest (36%). The forests in the north of Thailand are mostly tropical deciduous which led the dry leaves being important sources of forest fire. Data of hotspot in this study derived from the NASA's Earth Observatory website with terra and aqua satellites. During 11 years, the total regional hotspot count in 8 provinces were found 114,015 hotspot counts with an average of 10,365 hotspots annually and peak in March which is about 58.4% of hotspot.

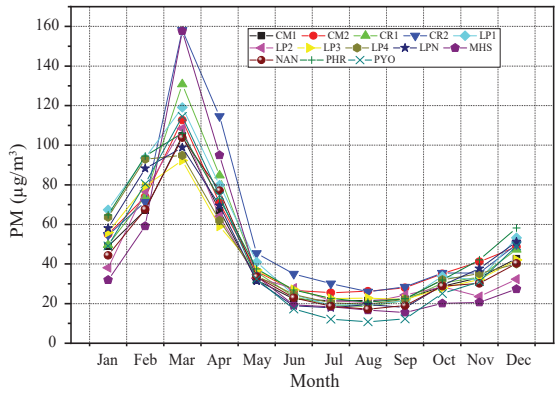
The highest count was recorded in Mae Hong Son province with 22.3% and 21.7% in Chiang Mai province respectively. The lowest count of wildfire, burnt area and hotspot were recorded in 2011, due to the meteorological with high amount and frequency of precipitation, thus the high relative humidity. These results are consistent with the forest fires and hotspot counts in the north of Thailand during the smoke episode which is higher than the non-episode.

3.2 *The mass concentration and variation of PM_{10} in upper Northern Thailand*

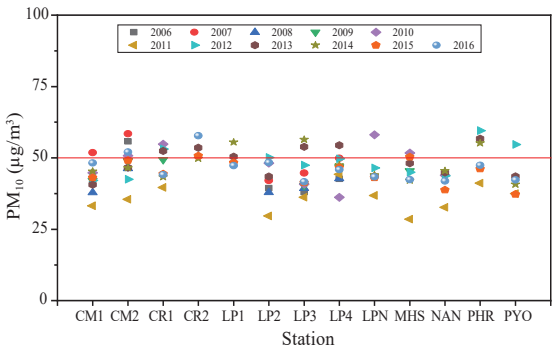
To determine the variation of PM_{10} in atmospheric, the hourly, daily and monthly PM_{10} concentration data from January 2010 to December 2016 from 13 stations in 8 provinces were analyzed in smoke episode (January–April) and non-smoke episode (May–December). The overall of PM_{10} concentration during 11 year in in the upper northern Thailand was demonstrated in Table 2. The average level of PM_{10} concentrations with an annual mean, episode mean and non-episode mean were 45.3 ± 43.8, 79.2 ± 56.8 and 28.7 ± 21.0 µg/m^3, respectively. The average PM_{10} concentration in

episode was higher than the level in non-episode with statistically significance ($p < 0.01$). The annual mean of PM_{10} level in the upper northern Thailand during the past 11 years was lower than the Thailand National Ambient Air Quality Standards (NAAQS) (50 μg/m^3), except in 2012 the annual mean higher than NAAQS with level of 51.2 ± 53.6 μg/m^3. The number of day that PM_{10} exceeded 120 μg/m^3 of NAAQS was highest in 2012 with 7.6%. These exceeded days were mostly obtained in dry season. The average of PM_{10} level and number of days exceeded the standard (120 μg/m^3) were recorded lowest in 2011 as well as forest fires and hotspot counts.

In details, the monthly and yearly variations of PM_{10} at all air pollutants monitoring stations during 11-y period shown in Figure 3. The monthly average of PM_{10} was recorded with the lowest level as 10.9 ± 8.0 μg/m^3 in August (non-episode) at PYO station and the highest level of 158.1 ± 104.9 μg/m^3 in March at CR2 station, which exceed of Thailand Air Quality Standard 120 μg/m^3. The pattern of PM_{10} variations were similar at all monitoring sites [Figure 3(a)]. Each year PM_{10} concentration was always high during January–April (episode) due to this period is dry season. The highest of PM_{10} level has been found in March in every year, except in 2011 when highest in February. In 2011, the northern, central, eastern and southern part of Thailand had early rain, which the significantly amounts of precipitations higher than normal in March, before the main flooding began between July and December [24]. Sirimongkonlertkul and team reported the low number of active fires due to the increased fluctuation



(a)



(b)

Figure 3: Trends and variability of PM_{10} concentrations (a) monthly variation and (b) yearly variation in each station during 2006–2016.

Table 2: Hourly rang and mean of PM_{10} concentrations in Northern Thailand during 2006–2016

Year	PM_{10} (μg/m^3) ± SD				Exceeded*
	Range	Annually	Episode	Non-episode	(%)
2006	5.0 – 500.0 (n = 43,108)	43.5 ± 39.0	66.5 ± 50.9	32.0 ± 24.4	2.6
2007	5.0 – 567.0 (n = 42,502)	49.5 ± 48.5	88.2 ± 62.5	30.3 ± 21.6	6.8
2008	0.0 – 368.0 (n = 48,280)	39.2 ± 35.2	67.5 ± 45.2	26.8 ± 19.7	2.0
2009	0.5 – 510.0 (n = 56,811)	42.8 ± 44.3	79.6 ± 64.4	28.7 ± 20.2	6.0
2010	1.0 – 631.0 (n = 84,690)	46.0 ± 46.7	88.0 ± 60.1	29.1 ± 24.6	6.7
2011	1.0 – 395.0 (n = 94,269)	36.3 ± 27.2	53.3 ± 31.7	28.7 ± 20.9	0.4
2012	1.0 – 628.0 (n = 95,159)	51.2 ± 53.6	92.2 ± 70.1	29.1 ± 19.6	7.6
2013	1.0 – 726.0 (n = 101,124)	48.6 ± 46.3	82.7 ± 58.5	30.5 ± 22.8	5.7
2014	1.0 – 593.0 (n = 103,908)	46.5 ± 41.6	82.2 ± 51.0	29.6 ± 20.8	5.0
2015	0.5 – 660.8 (n = 97,399)	45.4 ± 44.9	77.8 ± 56.1	25.9 ± 17.9	4.6
2016	0.0 – 535.0 (n = 108,483)	46.3 ± 43.4	83.3 ± 52.3	27.2 ± 19.2	5.3
Average	0.0 – 726.0 (n = 875,733)	45.3 ± 43.8	79.2 ± 56.8	28.7 ± 21.0	4.8

*The percentage of days for PM_{10} concentration exceeded the standard (Thailand NAAQS = 120 μg/m^3).

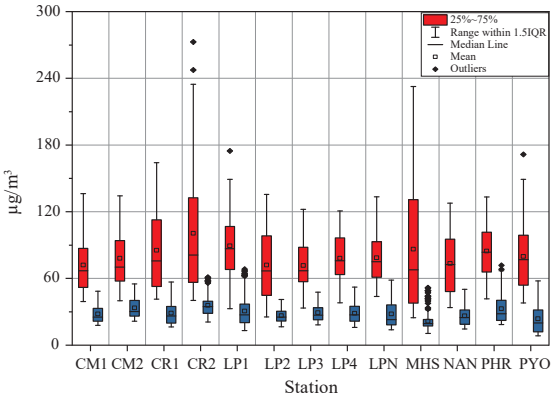


Figure 4: Boxplot of PM_{10} concentrations during the smoke episode (red color) and the non-smoke episode (blue color) in each station during 2006–2016.

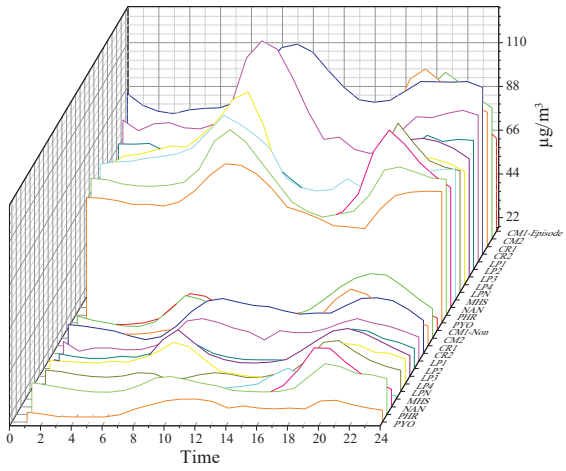


Figure 5: Diurnal variations of PM_{10} concentration during different episodes at 13 air pollutants monitoring stations of years 2006–2016.

in climate caused by La Niña in 2011 [25]. The annual of PM_{10} concentration in each station exceeded the standard in some years whereas NAN station has not been exceeded the standard [Figure 3(b)]. In 2013, the 6 stations were found that the annual of PM_{10} concentrations exceeded the standard. The box plot in Figure 4 illustrated the range, median, mean of PM_{10} concentration in each monitoring station. All of 13 stations were found that the concentration of PM_{10} during smoke episode higher than the non-episode with statistically significance ($p < 0.01$). The station represented the highest of annual mean, episode and non-episode mean where was CR2 station with 58.4 ± 61.4, 100.8 ± 84.4 and 36.6.1 ± 25.4 µg/m^3, respectively. During burning season, the PM_{10} concentration, forest fire and hotspot counts were found a significant correlation and to increase precipitously from January to March, the same trend pattern was observed every year. Furthermore, the meteorological factors in episode period were different from those in non-episode period such as relative humidity, temperature, wind speed and precipitation. In addition, the topography of the north of Thailand is mostly mountains and basins, especially Chiang Mai, Chiang Rai, Lamphun and Lampang province basin [26], [27], which give rise to the temperature inversions in smoke episode or the boundary layer of mixing height due to low wind speeds (0.72 ± 0.77 m/s) that indicated the stable atmosphere as previously report [28].

Hourly variation of PM_{10} concentrations in March during 2010–2016 were presented in Figure 5. Day time period (7:00–18.00) and night time period (19:00–6:00) of PM_{10} concentrations were observed. Day time period showed most obvious variations of low and high concentrations, while night time period had a few obvious variations. The highest and lowest hourly PM_{10} concentration were found during daytime as 306.1 µg/m^3 in 2010 and night time as 4.3 µg/m^3 in 2011, respectively. In dry season, peaks of PM_{10} concentration during daytime were higher than nighttime with most statistically significance ($p < 0.05$) in most stations such as LP1, CM1 and MHS station. However, some stations such as Nan and LPN station were not significant difference ($p < 0.05$). While in wet season, peaks of PM_{10} concentration during daytime and nighttime were found not significance difference ($p < 0.05$). Forest fires and open burned from human activities during daytime in dry season are the cause that impact PM_{10} concentration. In addition, the density of traffic during daytime period is more than nighttime period. Several previously researches reported the motor vehicles emit several pollutants such as particulate, carbon monoxide, nitrogen oxides which able to harmful to human health and the environment [8].

3.3 *Atmospheric pollutants variation and theirs correlation with meteorological*

The pollutants, i.e., NO, NO_2, NO_X, SO_2, O_3, and CO were measured one hour continuously during 11 years

period at 12 stations (except CR2 station), the results were presented in Table 3. The highest concentrations of NO, NO_x and O_3 were found in 2010 with 285, 366 and 177 ppb, respectively. While the highest concentrations of SO_2 and CO were found in 2014 with 87.7 ppb and 6.35 ppm, respectively, the highest level of NO_2 was 148 ppb in 2012. The variability of atmospheric pollutant concentrations depends on the specific emissions and general meteorological conditions. NO_X (NO_2+NO) is a primary and O_3 is a secondary contaminant that originates in the atmosphere through a set of complex reactions [29]. Figure 6 shows the daily variation of the hourly mean concentrations of PM_{10}, CO, O_3, SO_2, NO and NO_2 from 2006 to 2016 in the upper northern Thailand. Figure 6(a) illustrates cleared diurnal variations of PM_{10} level showing a bimodal pattern with peaks during 8:00–10:00 as well as 20:00–22:00 and the similar bimodal pattern was observed every year. PM_{10} concentration generally decreased from 23:00 to 6:00, after that the level increased from 7:00 and peaked at 9:00–11:00. This pattern of PM_{10} concentration with peaks during day period (9:00–11:00) and night period (20:00–22:00) was the same as Beijing city investigation [30]. Likewise, diurnal variations of CO, NO and NO_2 concentrations were the same bimodal pattern with PM_{10} shown in Figure 6(b), (e), (f). CO, NO and NO_2 level entirely increased from 5:00 until peak at 8:00– 9:00 and then decreased from 10:00 to 15:00. After that their levels were increased from 16.00 and peak at 19:00–21:00. The bimodal pattern of PM_{10}, CO, NO and NO_2 concentrations showed rush hour peaks in morning and evening time. The concentrations of CO, NO and NO_2 at night time (during 19.00–20.00) were slightly increased which caused from vehicle emissions during evening rush hour. Figure 6(c) shows daily pattern of O_3 concentration. During the day, O_3 concentration was sharply increased at 8.00 until maximum at 15.00. After that the O_3 concentration was decreased after sunset to the next morning. Furthermore, the meteorological data were obtained the mean of temperature and relative humidity were 25.4

Table 3: Mean hourly gaseous pollutants measurements during 2010–2016 in the upper northern of Thailand

Year	CO	O_3	NO	NO_x	NO_2	SO_2
	(ppm)	(ppb)	(ppb)	(ppb)	(ppb)	(ppb)
2006	0.52 ± 0.49 (n=43,108)	16.0 ± 16.4 (n=43,108)	4.2 ± 7.0 (n=43,108)	11.6 ± 13.1 (n=43,108)	7.5 ± 8.2 (n=43,108)	0.8 ± 1.2 (n=43,108)
2007	0.59 ± 0.59 (n=42,502)	16.5 ± 17.2 (n=42,502)	5.8 ± 9.8 (n=42,502)	14.5 ± 15.9 (n=42,502)	8.8 ± 9.8 (n=42,502)	0.9 ± 1.1 (n=42,502)
2008	0.49 ± 0.46 (n=48,280)	18.0 ± 17.5 (n=48,280)	3.7 ± 6.7 (n=42,592)	11.0 ± 13.6 (n=42,592)	7.2 ± 9.0 (n=42,592)	0.8 ± 1.3 (n=42,592)
2009	0.47 ± 0.43 (n=62,221)	19.1 ± 17.4 (n=62,221)	2.4 ± 5.5 (n=39,367)	7.9 ± 11.3 (n=39,367)	5.7 ± 7.2 (n=39,367)	0.7 ± 1.1 (n=44,777)
2010	0.54 ± 0.44 (n=78,100)	20.4 ± 18.9 (n=80,621)	3.3 ± 7.1 (n=64,386)	9.9 ± 14.0 (n=64,388)	6.8 ± 8.6 (n=64,406)	0.8 ± 1.2 (n=63,210)
2011	0.47 ± 0.33 (n=87,034)	19.0 ± 15.9 (n=84,612)	3.0 ± 5.5 (n=67,729)	8.9 ± 10.6 (n=67,729)	6.0 ± 6.7 (n=67,735)	1.1 ± 1.2 (n=70,127)
2012	0.55 ± 0.43 (n=85,780)	21.2 ± 19.4 (n=82,375)	3.7 ± 6.6 (n=67,254)	10.8 ± 13.8 (n=67,254)	7.2 ± 9.4 (n=67,340)	1.4 ± 1.4 (n=66,580)
2013	0.58 ± 0.36 (n=86,288)	23.7 ± 19.3 (n=90,526)	2.9 ± 4.8 (n=71,523)	10.2 ± 11.4 (n=71,522)	7.4 ± 8.3 (n=71,524)	1.5 ± 1.4 (n=70,601)
2014	0.58 ± 0.37 (n=79,281)	23.2 ± 19.6 (n=88,939)	2.7 ± 4.8 (n=74,958)	9.8 ± 10.6 (n=74,957)	7.2 ± 7.4 (n=74,961)	1.2 ± 1.4 (n=75,327)
2015	0.62 ± 0.40 (n=75,237)	26.4 ± 20.6 (n=74,182)	3.5 ± 7.2 (n=26,445)	14.8 ± 15.7 (n=26,445)	11.4 ± 10.2 (n=26,445)	1.7 ± 1.7 (n=72,742)
2016	0.58 ± 0.48 (n=80,865)	25.0 ± 21.1 (n=88,105)	3.6 ± 6.1 (n=7,371)	9.6 ± 11.0 (n=7,371)	6.1 ± 6.1 (n=7,371)	1.2 ± 1.5 (n=80,235)
Average	**0.55 ± 0.43 (n=768,696)**	**21.5 ± 19.1 (n=785,471)**	**3.4 ± 6.4 (n=54,235)**	**10.6 ± 12.8 (n=547,235)**	**7.2 ± 8.5 (n=54,7351)**	**1.1 ± 1.4 (n=671,801)**

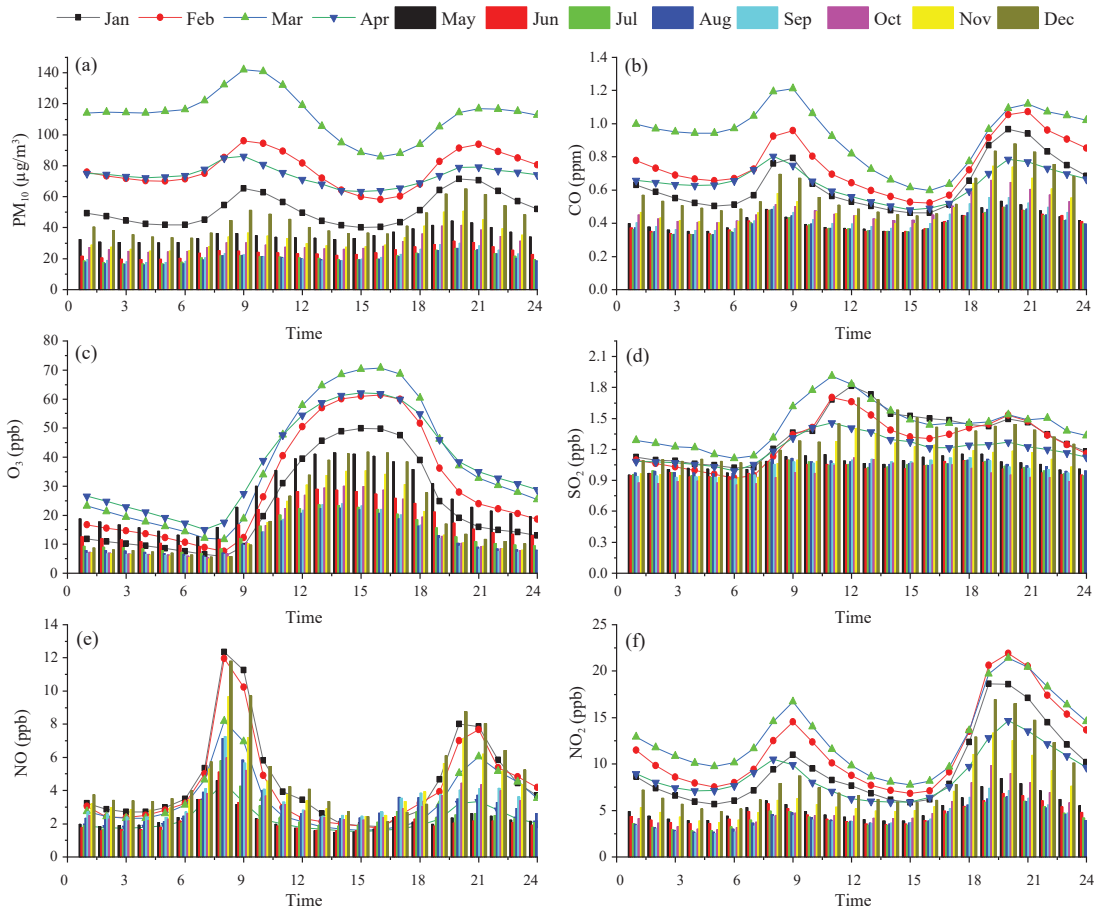


Figure 6: Diurnal variations of PM_{10} (a), CO (b), O_3 (c), SO_2 (d), NO (e) and NO_2 (f) concentration during 2006–2016 in the upper Northern Thailand.

± 6.4 – 27.2 ± 5.3°C and 65.5 ± 22.9 – 78.6 ± 18.1%, respectively. The average pressure and wind speed were 91.8 ± 10.4 – 97.4 ± 0.8 kPa and 0.7 ± 0.6 – 9.0 ± 1.0 m/s, respectively. Therefore, the means relative humidity were recorded in dry season and wet season with as 64.4 ± 22.3 and 82.3 ± 14.6%, respectively, while the accumulated rainfall ranged in dry season as 0.0–70.0 mm. and wet season as 0.0–413.8 mm. In dry season, the North of Thailand had inversion or stagnant meteorological conditions with low relative humidity, air pressure, dew point temperature and light winds [21]. Moreover, the topography of the northern Thailand is consisted of high mountains and a central plain resulting in pollutants building up over an area. These factors were influencing ambient particulate matter concentration [31].

The correlation coefficients between average hourly ambient air pollutants level and meteorological parameters were analyzed by Pearson correlation analysis as seen in Table 4. The negative relationships were found between relative humidity and pollutants ($p < 0.01$). Same as the result reported by Agudelo–Castaneda that the relationship can be explained by the influence of the transportation of new air masses over the area which can bring clear atmospheric air and decrease the cumulative concentrations of these pollutants [32].

This is consistent with the negative correlation between wind speed and air pollutants ($p < 0.01$) including PM_{10}, CO, NO and SO_2. Furthermore, there was a positive correlation of the association of CO, NO, NOx, NO_2, SO_2 and O_3 with PM_{10} ($p < 0.01$) and

Table 4: Pearson correlation of ambient air pollutants and meteorological parameters in 2006-2016: WS = wind speed, WD = wind direct, T = temperature, RH = relative humidity (%), GN = global radiation, P = pressure

	CO	NO	NOx	NO_2	SO_2	O_3	WS	WD	T	RH	GN	P	Rain		Mean	S.D.	N
PM_{10}	.557**	.145**	.365**	.444**	.155**	.261**	–.038**	.013**	–.010**	–.299**	–.028**	–.019**	–.035**	PM_{10}	45.3	43.8	869,844
CO		.382**	.595**	.608**	.148**	.021**	–.018**	–.026**	–.096**	–.130**	–.104**	–.066**	–.007**	CO	0.5	0.4	754,644
NO			.814**	.476**	.168**	–.238**	–.033**	–.065**	–.150**	.028**	–.075**	.056**	–.006**	NO	3.4	6.4	532,547
NOx				.896**	.182**	–.134**	.095**	–.047**	–.083**	–.149**	–.124**	.087**	–.010**	NOx	10.6	12.8	532,545
NO_2					.147**	–.022**	.169**	–.022**	–.010**	–.248**	–.129**	.091**	–.010**	NO_2	7.2	8.5	532,739
SO_2						.102**	–.072**	–.032**	.004**	–.105**	.063**	–.100**	.011**	SO_2	1.1	1.4	658,687
O_3							.244**	.042**	.410**	–.742**	.485**	–.086**	–.016**	O_3	21.5	19.1	769,415
WS								.006**	.194**	–.291**	.177**	–.029**	–.002	WS	0.9	1.3	904,705
WD									.041**	–.028**	–.003*	.027**	–.006**	WD	179.9	102.5	856,533
T										–.514**	.534**	–.017**	–.026**	T	26.5	7.7	892,939
RH											–.498**	–.033**	.042**	RH	73.6	20.8	873,138
GN												–.004**	–.009**	GN	173.2	266.0	625,010
RN												–.049**	–.001	RN	124.3	171.5	631,904
P													–.082**	P	976.9	128.6	798,710
**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).														Rain	0.3	3.2	864,833

the nitrogen oxides (NO, NOx and NO_2) presented a positively significant correlation with CO ($p < 0.01$). These results can indicated the road-traffic origin for these pollutants [30]. The exposure of atmospheric pollutants in Northern Thailand is not only from vehicle sources but also from biomass burning during the dry season.

3.4 *Atmospheric pollutants variation and theirs correlation with meteorological*

Health risk assessment (HRA) is the process for estimating the nature and probability of adverse health effects in humans who may be exposed to hazardous substance. The HRA can be evaluated by the Hazard quotient (HQ) for risk characterization of non-carcinogenic substances [33]. The Hazard Quotient (HQ) is used to assess the potential exposure to a substance and the level that no adverse effects are expected. The hazard index (HI) is equal to the sum of HQ and should be calculated for each type of exposure period and pathway [20]. HQ to be less than 1 is suggested as an acceptable level of non-carcinogenic adverse health risk except for a given air toxic. The potential for adverse health risk increases when HQ greater than the reference concentration ($HQ \geq 1$) [34]. The HQ level of CO, O_3 and PM_{10} ranged from 0.005–0.026, 0.08–0.47 and 0.22–3.16, respectively. The highest level of HQ of CO was found 0.040 at CM2 station on March 2007 and the highest HQ of O_3 shown 0.63 at LP4 station on March 2016. At CR2 station represents the highest value of $HIPM_{10}$ with 5.32 on March 2012. All HQ values of pollutant were sharply increased during the smoke episode (January to April), especially in March. In 11 years past, HQ and HI values during episode and non-episode in each station was shown in Table 5. In part of monthly mean of HQ values in each station, the HQ of CO values did not exceed 0.2 at all station in both episodes. However, HQ of O_3 values were exceeded 0.2 during episode period at all stations but almost HQ_{03} values during non-episode were not exceeded 0.2. Whilst HQ of PM_{10} values were exceeded 0.2 at all stations both episodes. HI value was summary of HQ_{CO}, HQ_{O3} and $HQPM_{10}$. The HI values at all pollutant monitoring stations during long term exposure exceeded 1.0 in episode smoke but the values not exceeded in non-episode period. Although the annual period shown the HI level exceeding 0.1 at almost stations except LP2 station, the $HQ \leq 0.2$ will be deemed insignificant. On the other hands the HQ is greater than 0.2 or the HI is greater than 1, the risk assessment should either be concern for potential exposure to contaminant concentrations in air pollutants and risk management should be taken [35]. In episode and non-episode of smoke, The HQ of CO, O_3 and PM_{10} were associated with the forest fire frequency and PM_{10} concentration with statistic significant ($p < 0.05$). The trend levels of forest fire, PM_{10} and HQ were similar in every year where the levels in episode period were higher than non-episode.

Table 5: Mean values of HQ and HI in 12 monitoring station*

Station	HQ						HI		
	CO		O_3		PM_{10}		Episode	Non	Annual
	Episode	Non	Episode	Non	Episode	Non			
CM1	0.014	0.008	0.31	0.18	1.44	0.56	1.77	0.75	1.04
CM2	0.021	0.014	0.26	0.14	1.56	0.67	1.84	0.83	1.12
CR1	0.018	0.011	0.28	0.15	1.70	0.58	2.00	0.74	1.10
LP1	0.020	0.012	0.40	0.21	1.82	0.61	2.24	0.84	1.24
LP2	0.012	0.007	0.28	0.12	1.43	0.53	1.72	0.66	0.99
LP3	0.014	0.008	0.33	0.15	1.43	0.59	1.77	0.74	1.04
LP4	0.007	0.006	0.37	0.16	1.56	0.58	1.94	0.75	1.12
LPN	0.014	0.007	0.34	0.21	1.57	0.57	1.93	0.78	1.09
MHS	0.015	0.009	0.27	0.12	1.72	0.43	2.01	0.56	1.00
NAN	0.015	0.009	0.33	0.18	1.48	0.52	1.82	0.71	1.00
PHR	0.015	0.009	0.34	0.19	1.70	0.66	2.06	0.86	1.17
PYO	0.012	0.007	0.38	0.20	1.59	0.48	1.98	0.69	1.05

* Except CR2 station where the data of CO and O_3 were not recorded.

4 Conclusions

The data of PM_{10} mass concentrations in 13 Northern Thailand from January 2006–December 2016 were analyzed. The highest of hotspot counts and PM_{10} concentrations were found in Mae Hong Son province in March. The hotspots had been relating PM_{10} with statistically significance ($p < 0.05$). Number of hotspot and PM_{10} concentration during smoke episode were significantly higher than those in non-smoke episode at all stations in every year. The daily variation of PM_{10}, CO, NO and NO_2 concentrations showed a bimodal pattern with peaks during 8:00–10:00, as well as 20:00–22:00, resulting from vehicle emission during rush hour in the morning and the evening. The concentration of CO, NO, NOx, NO_2 and O_3 were positive correlated with PM_{10} which represented the traffic sources of these pollutants. Health risk analysis showed among the atmospheric pollutants considering PM_{10}, CO and O_3 during smoke episode have the potential to cause non-carcinogenic risks (HI > 1) to population in Northern Thailand. These results would be seriously concerned the potential for health effects.

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