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THE EFFECT OF SEASONAL VARIATION AND METEOROLOGICAL DATA ON PM10 CONCENTRATIONS IN NORTHERN THAILAND

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ABSTRACT: This study examines emission sources and meteorological data affecting ambient concentrations of pollution haze in Northern Thailand on the basis of particulate matter (PM10) concentrations monitored and collected by Thailand's Pollution Control Department over a three-year period at thirteen stations in eight provinces. Increasing pollution and its major emission sources have been analyzed to reflect the seasonal variation of meteorological data over the periods of dry and rainy seasons. The results show that daily PM10 concentrations were at their highest levels during the dry season from January to April. In the course of a three-year time span, from 2015 to 2017, almost all monitoring stations recorded average PM10 concentration levels that were approximately 1 to 3 times higher than the Thailand's daily ambient air quality standard (120 μg/m^3). It was also observed that the average PM10 concentrations in areas under study were significantly higher than the average air quality recorded during the rainy season. The meteorological data, including temperature and winds blowing from the southerly and southeasterly directions, were significantly related to the increase of average PM10 concentrations. By contrast, the relative humidity and the wind speed were significantly related with the decrease of average PM10 concentrations. Forest fires and agricultural waste burning have been identified as the major sources of PM10 concentration in each site.

Keywords: Particulate matter, Haze, Seasonal variation, Source analysis, Thailand

1. INTRODUCTION

For more than fifteen years, the haze pollution has been a serious problem during dry seasons in Northern Thailand [1]-[7]. Emission sources are forest fires, biomass burning, motor vehicles, solid waste burning and some industries [2]. The haze pollution has adverse effects on transportation by causing visibility problems for air travel. More importantly, the haze pollution also damages the human respiratory systems by high concentrations of airborne particulates below 10 microns (PM10) [3], [8]. Likewise, a significantly negative impact of PM10 depositions is observed on fruits, vegetables and vegetation in general [3].

In 2016, Thailand's pollution reports showed that the 24-hour average of repairable suspended particulate matter (RSPM or PM10) in Northern Thailand exceeded on many days the country's ambient air quality standard of 120 micrograms per cubic meter (μg/m^3), reaching the peak concentration at 317 ug/m3 during the dry season from January to April [9]. Forest fires alone accounted for 70% of observed PM10 concentrations [10]. Other factors affecting PM10 concentrations included geography, seasonal weather variations and meteorological conditions [1], [2], [4], [8].

In this study, average PM10 concentrations and emission sources are analyzed on the basis of the meteorological data and haze pollution during dry and rainy seasons in Thailand's 8 Northern provinces. The relationship between average PM10 concentrations and the meteorological data has been investigated at 13 monitoring stations, located in 8 Northern provinces and operated by Thailand's Pollution Control Department (PCD). The study also examines the relationship between emission sources and the meteorological data recorded by the selected monitoring stations.

2. MATERIALS AND METHODS

2.1 Description of the Study Area and Monitoring Stations

The area selected for this study covered the following provinces in Northern Thailand: Chiang Mai (20,107 km^2), Mae Hong Son (12,681 km^2), Lampang (12,534 km^2), Chiang Rai (11,678 km^2), Nan (11,472 km^2), Phrae (6,539 km^2) Phayao (6,335 km^2) and Lamphun (4,506 km^2). Most of the study area is located in valleys surrounded by mountain ranges. The area has thirteen air monitoring stations managed by Thailand's Pollution Control Department (PCD). The map of the geographical position of the sites within the study areas is shown in Fig. 1. The coordinates and the description of monitoring stations are presented in Table 1.

Fig. 1 Study area and monitoring stations

Table 1 Coordinates of study sites and monitoring stations

Province	Monitoring Station (Code)	Latitude	Longitude	Characteristics
Chiang Rai	Wiang Muang (WM)	19° 54' 33" N	99° 49' 24" E	Suburban, 5 m distance to the road.
	Wiang Phang Kham (WPK)	20° 25' 38" N	99° 53' 2" E	Suburban, 5 m distance to the main road.
Chiang Mai	Chang Phueak (CP)	18° 50' 26" N	98° 58' 11" E	Suburban, 150 m distance to the road.
	Si Phum (S)	18° 47' 27 " N	98° 59' 24" E	Urban, close to a busy road.
Lampang	Phra Bat (PB)	18° 16' 42" N	99° 30' 24" E	Suburban, 300 m distance to the road, close to the airport.
	Sop Pat (SP)	18° 15' 3" N	99° 45' 50" E	Rural, 5 m distance to the quiet road, a park surrounding.
	Ban Dong (BD)	18° 25' 37 " N	99° 45' 27" E	Rural, a park surrounding.
	Mae Mo (MM)	18° 16' 57 " N	99° 39' 35" E	Rural, a park surrounding.
Lamphun	Nai Muang (NM)	18° 34' 3" N	99° 0' 29" E	Suburban, 100 m distance to the road.

Province	Monitoring Station (Code)	Latitude	Longitude	Characteristics
Mae Hong Son	Chong Kham (CK)	19° 18' 16" N	97° 58' 18" E	Suburban, a park surrounding, close to the airport.
Nan	Nai Wiang (NW)	99° 0' 29" N	100° 46' 35" E	Suburban, 100 m distance to the road.
Phrea	Na Chak (NC)	18° 7' 42" N	100° 9' 45" E	Suburban, 100 m distance to the road, a park surrounding.
Phayao	Wiang (W)	19° 10' 0" N	99° 53' 49" E	Suburban, 100 m distance to the road.

2.2 PM10 Concentration and Meteorological Data Analysis

Hourly PM10 concentrations at the 13 monitoring stations were obtained from the PCD monitoring system during the January-April dry season and the June-September rainy season from 2015 to 2017. Methods of Beta Ray attenuation and Tapered Element Oscillating Microbalance (TEOM) were used for measuring PM10 concentrations at the monitoring stations. That has made it possible to obtain differences of average PM10 concentrations during dry and rainy seasons.

The hourly meteorological data, including wind speed, wind direction, temperature and relative humidity, were obtained from the PCD's air monitoring stations.

2.3 Source Analysis

Data on burnt areas were obtained from the Geo-Informatics and Space Technology Development Agency (Public Organization), or GISTDA, of Thailand's Ministry of Natural Resources and Environment. A linear regression analysis is used to investigate the relationship between average PM10 concentrations and burnt areas. That relationship is also examined on the basis of fire hotspots data, obtained from Thailand's Forest Fire Control Division.

The BD monitoring station in the Lampang Province has been selected to investigate that relationship. For 29% of the days during a three-year period, the Lampang Province exceeded the average Thai PM 10 24-hour standard, followed by the provinces of Chiang Rai (22%), Chiang Mai (15%), Mae Hong Son (13%), Phayao (7%), Prae (5%). Nan and Lamphun provinces (4%) showed the lowest pollution levels. The BD monitoring station is in park surroundings of a rural area, and it could serve as a reference site.

3. RESULTS

3.1 Concentration and Seasonal Variation of PM10

Figure 2 shows average annual PM10 concentrations during dry and rainy seasons in Thailand's 8 Northern provinces from 2015 to 2017. That evidence indicates that the Thai ambient PM10 annual standard of 50 micrograms per cubic meter (ug/m^3) was not exceeded. However, during those three years, the annual averages of PM10 concentrations were higher in dry seasons than in rainy seasons. In addition, Figure 3 shows that the proportion of days (%) when PM10 concentrations (in 24-hour averages) exceeded the Thai ambient PM10 24-hour average standard (<120 µg/m^3) in each monitoring station was approximately in the range of 8-23% for 2015, 6-30% for 2016 and 0-19% for 2017.

The PM10 concentration averages in dry and rainy seasons are presented in Figure 4. A three-year peak of the average PM10 concentration is shown at the CK monitoring station (210 ug/m^3).

In terms of seasonal variations, average PM10 concentrations during the dry season were significantly higher than during the rainy season ($P<0.001$, t-test). The standard deviations (SD) of average PM10 concentrations during dry and rainy seasons were 73.38±13.05 and 20.05±5.32, respectively. Results of the test are shown in Table 2.

Relationships between average PM10 concentrations and meteorological data, including wind speed, wind direction, temperature and relative humidity, were examined using datasets of the BD monitoring station in the Lampang Province. That is where the highest average of PM10 concentrations was found. The correlation coefficients of PM10 concentrations and meteorological data were the highest for relative humidity (P<0.001), followed by wind speed (P=0.048), temperature (P=0.034) and wind direction from south (P=0.001) and southeast (P=0.01). The linear equation model of these relationships is shown as Eq. (1).

$$Y_{PM10con.} = 159.457 - 1.723X_{RH} - 13.644X_{ws} + 0.868X_{Temp} + 9.538X_{wd5} + 6.861X_{wd4} \quad (1)$$

Where $Y_{PM10con.}$ is PM10 concentration in ug/m^3; X_{RH} is relative humidity (%); X_{ws} is wind speed in m/s; X_{Temp} is temperature in Celsius degrees; X_{wd5} is wind direction from the south; X_{wd4} is wind direction from the southeast.

The values of y-intercepts in above equations could be interpreted as a relationship between average PM10 concentrations and meteorological data. The relative humidity and wind speed show a significantly inverse relationship with average PM10 concentrations (P<0.05), while the average PM10 concentrations are positively related to changes in temperature and southerly and south-easterly winds (P<0.05).

Table 2 Results of *t-test* comparing average PM10 concentrations in dry and rainy seasons

Parameter	PM10 in dry season	PM10 in rainy season
Mean	73.38	20.05
Std. Deviation	13.05	5.32
t	24.522	
df	38	
p-value	0.001	

3.2 Source Analysis of PM10 Concentration

Most forest fires in Northern Thailand are observed during the dry season. The data collected by the Department of Forestry in 2017 showed that the major emission sources of haze pollution were forest fires during the harvesting of non-timber products (75.21%), followed by hunting (7.76%) and agricultural burning (4.04%). Other factors accounted for 12.99% of haze pollution.

From the investigation of emission sources in the selected monitoring stations, it was found that the southeasterly wind was blowing approximately 35.5% of the time at the speed of 0.5-5.7 m/s. The fire hotspot is detected by the MODIS satellite system during the dry season in a forest area that lies southeast of the monitoring station (0.8 km). That could mean that some of the PM10 concentration in that area is caused by the forest fire. It is also possible that the claim wind, blowing for the rest of the year (64.5% of the time), may not be the main PM10 emission source in the dry season. A further study, therefore, should focus on the wind direction and the PM10 concentration during the dry season periods.

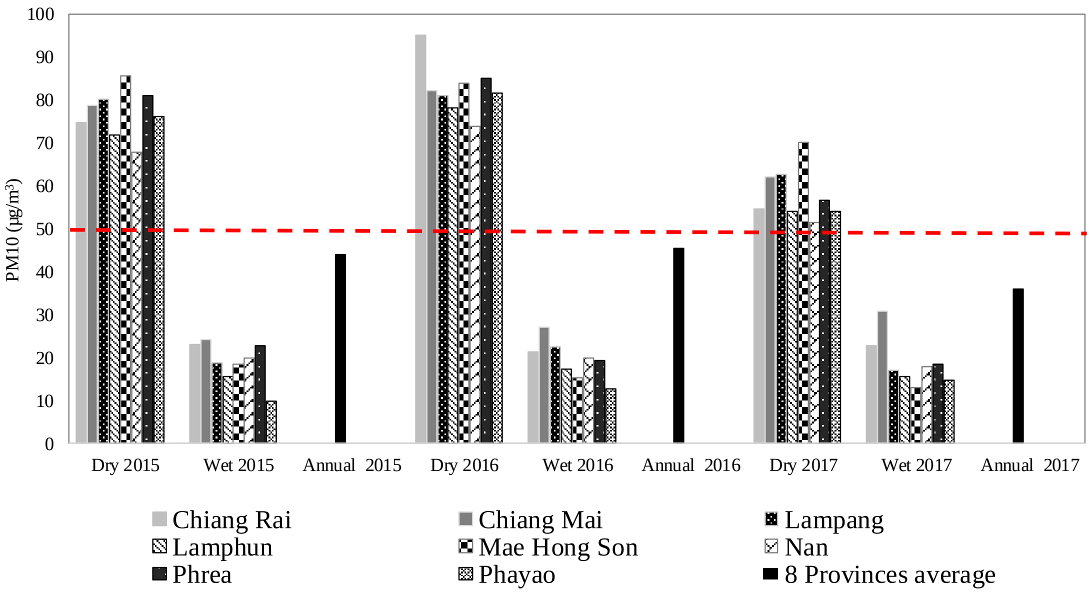

Fig. 2 Average annual PM10 concentrations in Northern Thailand.

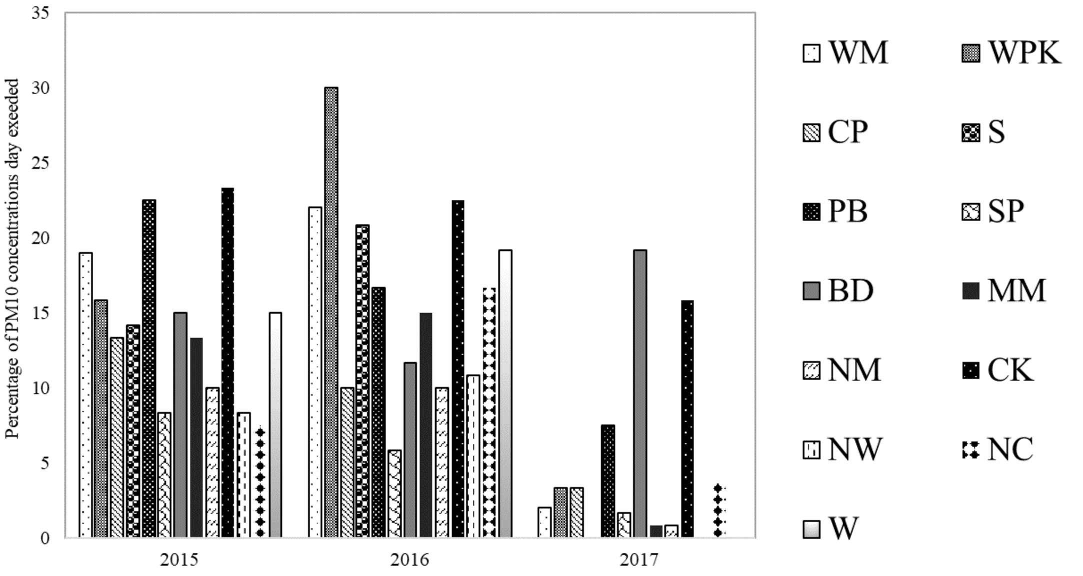

Fig. 3 Percentage by which daily average PM10 concentration exceeded standard in 13 monitoring stations.

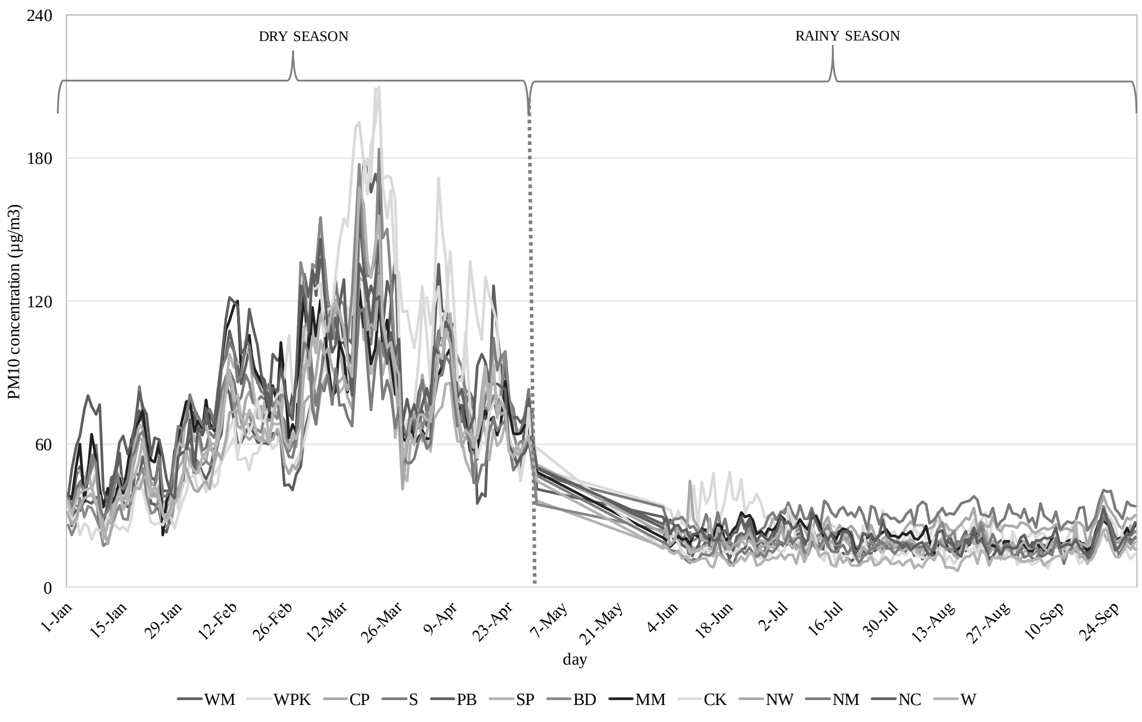

Fig. 4 Daily average of PM10 concentration during dry and rainy seasons at 13 monitoring stations in Northern Thailand

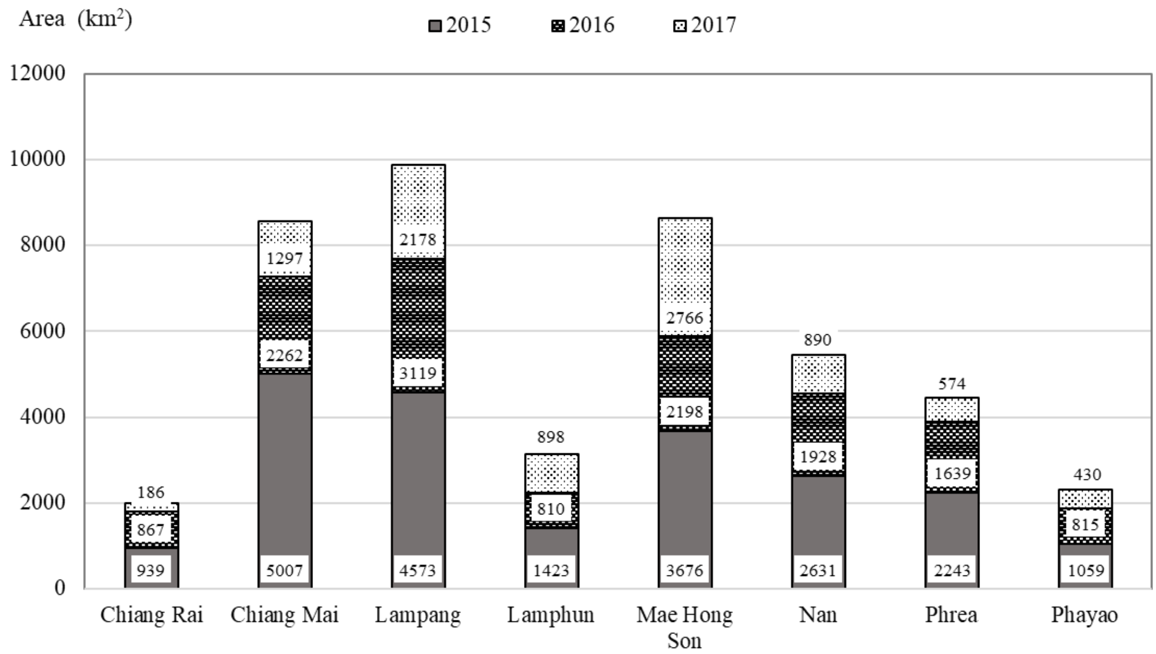

Fig. 5 Burnt areas of 8 provinces in Northern Thailand (unit: km^2)

Table 3 Amount of fire hotspots in Northern Thailand (unit: point)

Year	Study area	Agricultural	Forest	Total
2015	Chiang Rai	74	714	8,236
	Chiang Mai	178	1,833	
	Lampang	192	606	
	Lamphun	57	309	
	Mae Hong Son	168	2,142	
	Nan	120	1,201	
	Phrea	110	319	
	Phayao	36	177	
2016	Chiang Rai	127	1,235	6,812
	Chiang Mai	134	758	
	Lampang	155	660	
	Lamphun	39	204	
	Mae Hong Son	87	1,252	
	Nan	66	977	
	Phrea	118	606	
	Phayao	82	312	
2017	Chiang Rai	38	115	5,200
	Chiang Mai	186	1,782	
	Lampang	189	465	
	Lamphun	49	276	
	Mae Hong Son	48	1,114	
	Nan	60	478	
	Phrea	55	244	
	Phayao	19	82	

In addition, the information of the burnt areas, detected by the Landsat 8 satellite images and presented by the GISTDA, showed increasing PM10 concentrations during the dry season. Burnt areas of 8 provinces in Northern Thailand is shown in Figure 4. The Pearson correlation analysis found a significant relationship between average PM10 concentrations and burnt areas in 8 provinces over the period from 2015 to 2017 ($P<0.05$). That was confirmed by the linear regression analysis showing that burnt areas were significantly and positively related to PM10 concentrations ($P<0.001$). The equation estimating that relationships is shown as Eq. (2).

$$Y_{PM10con.} = 0.04X_{area} + 65.108 \qquad (2)$$

Where $Y_{PM10con.}$ is PM10 concentration in ug/m^3 and X_{area} is burnt area in km^2. The values of y-intercept in the equation above could be taken to represent the PM10 concentration in burnt areas.

The data in Table 3, obtained from Thailand's Forest Fire Control Division, show fire hotspots (in points) in the study area from 2015 to 2017, indicating that forest fires and the agricultural waste burning remain the major sources of pollution. In particular, as Eq. 3 shows, increasing average PM10 concentrations are significantly and positively related to fire hotspots in each area ($P<0.05$).

$$Y_{PM10con.} = 0.049X_{H} + 62.289 \qquad (3)$$

Where $Y_{PM10con.}$ is PM10 concentration in µg/m^3 and X_H is the amount (in points) of fire hotspots.

4. CONCLUSION

This study is based on a 3-year dataset from 2015 to 2017, collected at 13 monitoring stations in Northern Thailand, to evaluate the sources and the seasonal variation of average PM10 concentrations. The results show that the average PM10 concentrations are significantly and positively related to burnt areas and the amount of fire hotspots in each location covered by this analysis. The highest level of PM10 concentration -- at 210 µg/m3 --during those three years was found in the period of dry season. Average dry season PM10 concentrations were significantly higher than those observed during the rainy season ($P<0.001$, t-test).

The increasing average PM10 concentrations were significantly related to meteorological data, such as temperature, southerly and southeasterly winds. On the other hand, relative humidity and wind speed were found to have a significantly inverse relationship with average PM10 concentrations. Average PM10 concentrations were significantly and positively related to increasing fire hotspots ($P<0.05$). The main sources of PM10 concentrations in the areas covered by this study were forest fires and agricultural waste burning.

The meteorological data indicate that seasonal changes and PM10 emission sources have to be taken together to investigate major causes of haze pollution.

5. ACKNOWLEDGEMENTS

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