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RESEARCH ARTICLE

Influence of the meteorological conditions and some pollutants on PM_{10} concentrations in Lamphun, Thailand

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Abstract

Particulate matter (PM) has been occurring regularly during the dry season in the upper north of Thailand including Lamphun Province that might be influenced by various factors including climatologic and other pollutants. This paper aims to investigate the climatologic and gaseous factors influencing the occurrence of PM_{10} concentration using Pollution Control Department (PCD) data. The secondary data of 2009 to 2017 obtained from the PCD was used for analysis. We used descriptive statistics, Pearson's correlation coefficient, multiple regression and graphic presentation using R program (R packages of 'open air' and 'ncdf4') and Microsoft Excel Spreadsheet®. In addition, the periodic measurement of $PM_{2.5}$ and PM_{10} were investigated to determine the ratio of $PM_{2.5}/PM_{10}$. The results indicated that haze episodes (daily PM_{10} concentration always over the PCD standard) normally occur during the dry season from February to April. The maximum concentration was always found in March. The PM_{10} concentration was negatively associated with relative humidity and temperature while the PM_{10} concentration showed a strongly positive association with CO and NO_2 concentration with correlation values of 0.70 and 0.57, respectively. Furthermore, we found CO and PM_{10} concentration was associated with ozone concentration. This finding will benefit local communities and the public health sector to provide a warning system for preparation and response plans to react to PM_{10} episodes in their responsible areas.

Keywords PM_{10} · Haze episode · Lamphun Province · Climatological factors

Introduction

Atmospheric pollution has become a significant challenge globally especially in the developing countries [1]. Air pollutants are generated mainly from natural, anthropogenic sources and emission sources, i.e., global urbanization, emissions from automobiles and industries, domestic fuel combustion, biomass burning, forest burning, construction etc. The increased concentrations of air pollutants impact vegetation, animal life, buildings and monuments, weather and climate and the aesthetic quality of human health and ecology [2] both directly and indirectly. The unhealthy effects of air pollution, such as heart disease, stroke, blood pressure, cardiovascular diseases [3, 4] and long term exposure to PM_{10} may lead to a markedly reduced life expectancy due to increased cardio-pulmonary and lung cancer mortality [5].This research investigated the characteristics of PM_{10} and their association with other pollutants and climatologic factors, that will help develop a warning system for health-related issues in the provinces. Many researchers have indicated that PM_{10} concentration was associated with health problems, for example, heart and blood pressure as reported by Dianat M, et al. They found PM_{10} had devastating effects on the heart and blood pressure probably due to the increased oxidative stress, decreased antioxidant enzymes, increased expression of iNOS mRNA level, lactate dehydrogenase (LDH) and xanthine oxidase in homogenized heart tissue with ischemia reperfusion in healthy rats [6, 7]. In addition, Neisi et al., also indicated that particulate matter (PM) affects lung function by observing inflammatory biomarkers and FVC [8]. Moreover, other researchers also reported that PM was harmful to human health in various endpoints of the diseases such as pneumonia [9, 10], respiratory and cardiovascular systems [11] and adverse health outcomes [12].

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PM is an important pollutant present in the atmosphere that can penetrate the respiratory system through the function of their aerodynamic diameter causing health hazards [13]. The concerns regarding PM, particularly $PM_{2.5}$ meaning PM of 2.5 μm or less in aerodynamic diameter [14] and PM_{10} (PM of 10 μm or less in aerodynamic diameter). Over two decades, northern Thailand presents seasonal haze during the dry season (January to April) [12]. PM comprises most of the air pollutants in upper northern Thailand during these periods. Both local and central governmental organizations have launched many measures to reduce the concentration of PM in northern Thailand. For example, the Chiang Mai Provincial Administrative Organization declared and launched the "must-watch 60 days", from February 20 to April 20 in 2018 - the period when fires are most likely to occur [15].

Lamphun Province is a small province located in the upper north of Thailand connected to Chiang Mai Province, which is the most popular tourist city in terms of Thai culture. The population totals 404,096 with a total area of 4506 km^2. The province is located between latitude 18° 00′ north and longitude 99°"east and is surrounded by mountains. In almost every dry season, haze is a main issue because of low airflow and temperature inversion causing numerous air pollutants to accumulate. Biomass burning is one of the major sources of PM_{10} concentration in the atmosphere detected in the Chiang Mai-Lamphun Basin [16–18]. The major sources of haze in this area are open biomass burning, particularly forest fires, as well as traffic emissions [17]. The occurrence of localized haze over the urban areas in northern Thailand, especially in Lamphun Province, has become a common feature for the past two decades. Haze regularly occurs during the north-east monsoon season and the transition period of cold weather and summer period in January to April yearly. The Thailand tropical climatic conditions result in extreme temperatures, rainfall and relative humidity. Haze episode is determined by high concentrations of PM_{10} over the ambient air quality standard recommended by the Pollution Control Department (PCD); the standard of PM_{10} for 24 h is 120 μg/m^3 [19]. The air quality index (AQI) is also used to determine air quality. The AQI standard is 100 using the calculation of concerned parameters, namely, SO_2, CO, NO_2, PM_{10} and O_3 as indicated in EPA methods [20]. In the past decade, PM_{10} concentrations in Lamphun have been monitored and over the limit during the dry season. This study used secondary data (2009–2017) obtained from the permanent monitoring station of the PCD. However, $PM_{2.5}$ measurement is not performed in the air quality monitoring station located in Lamphun Province. The measurement of $PM_{2.5}$ and PM_{10} was conducted for three consecutive days in two stations to obtain the proportion of $PM_{2.5}$ to PM_{10}. In addition, understanding PM concentration and its behavior will benefits local organizations and residents to effectively respond to the situation. Moreover, a warning system can be created to develop future local response plans, because the Thai weather forecasting system is available and accessible. Understanding the relationship of pollutants and climatologic factors comprise basic information to determine air quality in this province.

Materials and methods

Data collection

The PCD ambient air quality data in Lamphun monitoring station from July 2009 to December 2017 was collected, indicating the air pollutant components were CO, SO_2, PM_{10}, NO_2, and O_3. The monitoring station location and its surrounding characteristics are illustrated in Fig. 1. In addition, the periodic measurement of $PM_{2.5}$ and PM_{10} was performed in two stations by researchers, one was used as the representative of an urban area (Muang Lamphun) and the other was a rural area (Pa Sang District) as presented in Table 1. To collect air samples, a personal pump was prepared and calibrated. Leland legacy-model (10 L/min) was used as the IMPACT Sampler PM Coarse sampling head. The air pump calibrated the flow rate using an electronic rotameter before and after the sampling. The sampling was conducted using the IMPACT Sampler PM Coarse connected to a 10 L/min-flow rate air pump. In addition, 37- and 47-mm diameter PTFE filters were used for $PM_{2.5–10}$ and $PM_{2.5}$ sampling instead. The sample was preserved with a container for UV-absorbing protection. The filters were weighted for pre- and posts ampling by ultra-microbalance, with 0.1 μg readability. The PM micrograms were calculated from the weighted mass difference divided by the air sampling volume, then PM concentration in micrograms per cubic meter (μg/m^3) was obtained. Quality Control (QC) was performed by following the Shewhart Control Chart method [21].

Data analysis

In general, the PCD air quality raw data was considered using QA /QC units before publishing. However, the obtained secondary data were also clean before analysis, and missing data and outliers were considered. Missing data were detected at 8.4% and only available data were used for this study. After the cleaning process, data were prepared using Excel software comprising the input for R code. R studio software was used for data analysis both descriptive statistics and correlation study. Statistical analysis, including descriptive statistics and Pearson's correlation coefficient were performed in the R-studio program using R packages, namely, 'OPENAIR' [22], and 'NCDF4' [23] providing a high level R interface for Network Common Data (NetCDF). Microsoft Excel Spreadsheet® was used to analyze the Stepwise Multiple Linear Regression (MLR) statistical model.

Fig. 1 The topographic map of Lamphun Province air quality monitoring station

Results

Characteristics of air quality in Lamphun from 2009 to 2017

The obtained data on air quality from PCD was monitored since 2009; the air quality data were available for only six months in 2009. The characteristics of air quality and climatologic data in Lamphun Province were classified by pollutant as shown in Table 2. The mean PM_{10} concentration for the 7.5-year period was 44.2 μg/m^3 ranging from 1 h concentrations 1.0–561.0 μg/m^3. During the study period, the maximum concentration was 4.6 times that of the acceptable level (Thailand National Ambient Air Quality Standards (NAAQS) of $PM_{10,}$ namely, 120 μg/m^3), while, other pollutants were acceptable when compared with the NAAQS except for the maximum concentration of ozone. Wind speed in this province was slightly low, at an average of 0.9 m/s. The temperature ranged from 6.3 to 42.2^o Celsius with an average relative humidity of 72%.

Table 3. shows the proportion of $PM_{2.5}$ to PM_{10} in this study ranged from 0.5–0.56 which is representative of the period of measurement (March). The proportion obtained from this study was slightly lower than that measured in China ranging from 0.58 to 0.71 [24]. Compared with the proportion of $PM_{2.5}$ to PM_{10} near the traffic roadway in India reported by Srimuruganandam and Shiva Nagendra, it ranged from 0.43 to 0.59, and the highest proportion was detected at night during winter season. This proportion was slightly higher than that of the Indian study [25]. The proportion of fine ($PM_{2.5}$) to coarse particles (PM_{10}) in the rural area (Pasang School) was slightly higher than that of the urban area (Chak Kham Khanathon School).

Table 1 Location of $PM_{2.5}$ and PM_{10} measurement in this study

Station name	Measurement Date	Coordinate		District
		Latitude	Longitude	
Chak Kham -Khanathon School (urban zone)	27 Mar – 30 Mar 2017	18.5919	99.0139	Muang Lamphun
Pa Sang School (rural zone)	27 Mar – 30 Mar 2017	18.5197	98.9336	Pa Sang District

Table 2 Description of characteristics of concern parameters collected during 2009–2017

Pollutants	Mean	SD	Min	Q1	Q3	Max	Standard
PM_{10} (24 h), μg/m^3	42.98	32.71	1.00	17.00	57.00	561.00	120 μg/m^3
CO(8 h), ppm	0.48	0.26	0.10	0.30	0.60	5.600	9 ppm
NO_2(1 h), ppb	6.43	4.56	1.00	2.00	8.00	98.00	170 ppb
SO_2(24 h), ppb	1.85	1.13	0.20	1.00	2.00	19.00	300 ppb
$O_{3\ (}$(8 h), ppb	24.82	10.78	1.00	10.00	35.00	127.00	70 ppb
Wind speed, m/s	0.82	0.34	0.00	0.30	1.10	8.20	–
Temperature, °C	26.98	2.90	6.30	24.20	30.20	42.60	–
Relative humidity, %	73.55	12.53	29.75	65.37	82.47	98.08	–
Pressure, mBar	730.00	3.47	677.00	728.00	73.00	746.00	–
Rainfall, mm	0.24	3.43	0.00	0.00	0.00	264.00	–

Time series analysis

The hourly PM_{10} concentration data from 2009 to 2017 was aggregated to weekly data as illustrated in Fig. 2. It indicated that the haze episode (identified by means of weekly PM_{10} exceeding the NAAQS) mostly occurred during the first quarter of the year (January to March) except in 2011. In 2011, a devastating flood occurred in many areas of Thailand, including Lamphun Province. However, PM_{10} peak concentrations in this province during the study period decreased possibly influenced by various factors such as climate parameters, policy factors or action plans. In Lamphun Province, the governor announced to reduce the number of haze days determined by number of days which PM_{10} concentration was higher than the NAAQS (>120 μg/m^3). The sources of PM were generated by many activities from both local areas and movement outside Lamphun areas. The control of biomass burning for 30–60 days during the high potential haze episode was launched and implemented. The regulation was enforced for the whole province. Mitigation measures might have reduced PM_{10} concentration. When considering hourly data for each day of the week, the PM_{10} concentrations were always high in the evening decreasing during the night time becoming slightly stable the rest of the day. The concentration during the day did not change much and the lowest concentration was found in the afternoon as illustrated in Fig. 3. When considering the monthly variation, PM_{10} concentrations increased after the new year reaching the maximum concentration in March and then sharply decreasing in May becoming slightly stable from May to September, which was classified as the rainy season in northern Thailand. PM_{10} concentration slightly increased after October of each year, the end of rainy season, until the end of the year.

When considering by hourly period (00–24 h), PM_{10} concentration was strongly related to the relative humidity and minimum PM_{10} concentration was detected in the afternoon at high temperature as illustrated in Fig. 4. The temperature negatively correlated to relative humidity (high temperature - low relative humidity).

Considering climatologic parameters, annual average temperature in 2011 was 25.4 °C and average relative humidity was 74.5%. Whereas, the annual average temperature and relative humidity in 2012 were 26.1 °C and 68.0%, respectively. The annual average PM_{10} concentration in 2011 was 36.9 with a maximum one hour concentration of 251 μg/m^3, while the annual average concentration in 2012 was 46.5 with maximum value of 381 μg/m^3 (Fig. 5). It indicated that when high temperature was detected during these years PM_{10} concentration would be dropped. However, ambient temperature did not differ during both years.

Correlation study

In this study, Pearson's correlation coefficient was calculated to determine the correlation of climatologic factors and other pollutants with PM_{10}concentration. In Lamphun Province, PM_{10} concentration showed a strongly positively correlation with CO and NO_2 concentrations with values (r) of 0.70 and

Table 3 The 24 average concentration of $PM_{2.5}$ and PM_{10} from the measurement during 27–30 April 2017

Station name	Average 24 h Concentration (μg/m^3)		Proportion of $PM_{2.5}/PM_{10}$
	$PM_{2.5}$	PM_{10}	
Chak Kham Khanathon School	80.2	158.5	0.50
Pa Sang School	58.8	104.8	0.56
PCD Standard	50.0	120.0	–

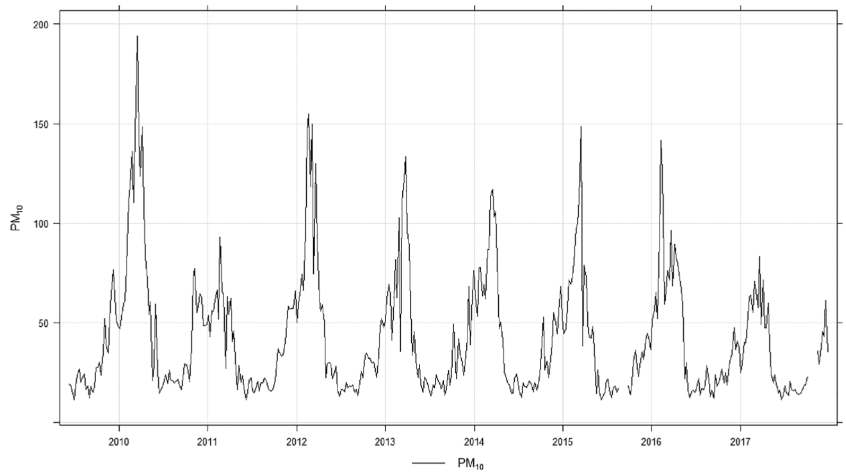


Fig. 2 Weekly mean PM_{10} concentration ($\mu g/m^3$) in Lamphun air quality monitoring station during 2009–2017

0.57, respectively as indicated in Fig. 6. This finding was interesting as PM_{10} and CO concentration was highly associated. In general, CO concentration occurred due to incomplete burning and combustion. The generated CO might be induced from biomass burning or exhaust emissions from vehicles using fossil fuels. The PM_{10} concentration was negatively correlated to relative humidity, temperature and wind speed with r values of 0.26, 0.12 and 0.14, respectively. For climate parameters, temperature strongly negatively correlated to relative humidity (r = 0.74). In general, many studies have indicated that ozone concentration always increased during the afternoon to evening. [26, 27]. In addition, different ozone concentrations might influence PM_{10} concentration, so this study analyzed the relationship of PM_{10} with CO in different ozone concentrations in terms of scatter diagrams as illustrated in Fig. 7. Different ozone concentrations generated a similar relationship between PM_{10} and CO. However, the increasing ozone concentration leaded the decreasing relationship as indicated in R^2 values (Coefficient of Determination), the R^2 values for lower ozone was 0.54 (ozone concentration ranges of 1–10 ppb) and 0.53 (ozone concentration ranges of 10–20 ppb). The R^2 values of higher ozone were 0.46 and 0.33 for ozone concentration of 20–35 ppb and 35–127 ppb, respectively. If ozone concentration was over, approximately 30 ppb, the association of PM_{10} concentration and CO was lower than 33%.

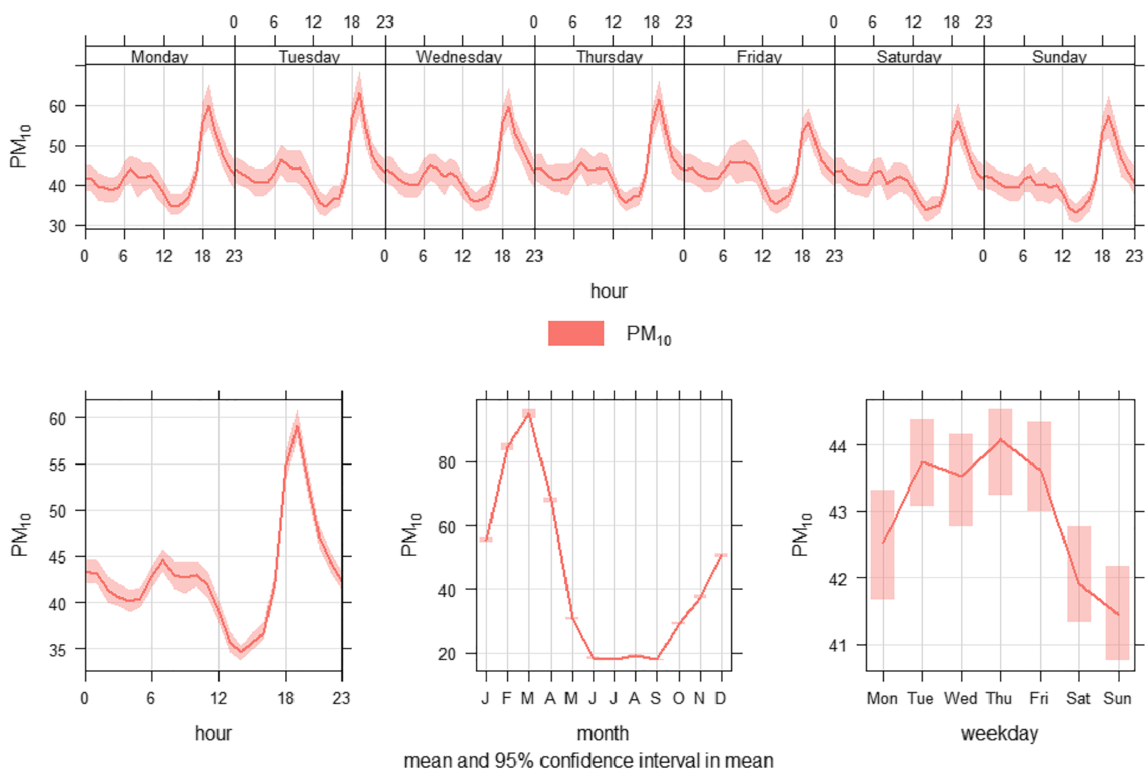


Fig. 3 Hourly, monthly, and weekday mean PM_{10} concentrations ($\mu g/m^3$) with 95% CI in Lamphun Province (2009–2017)

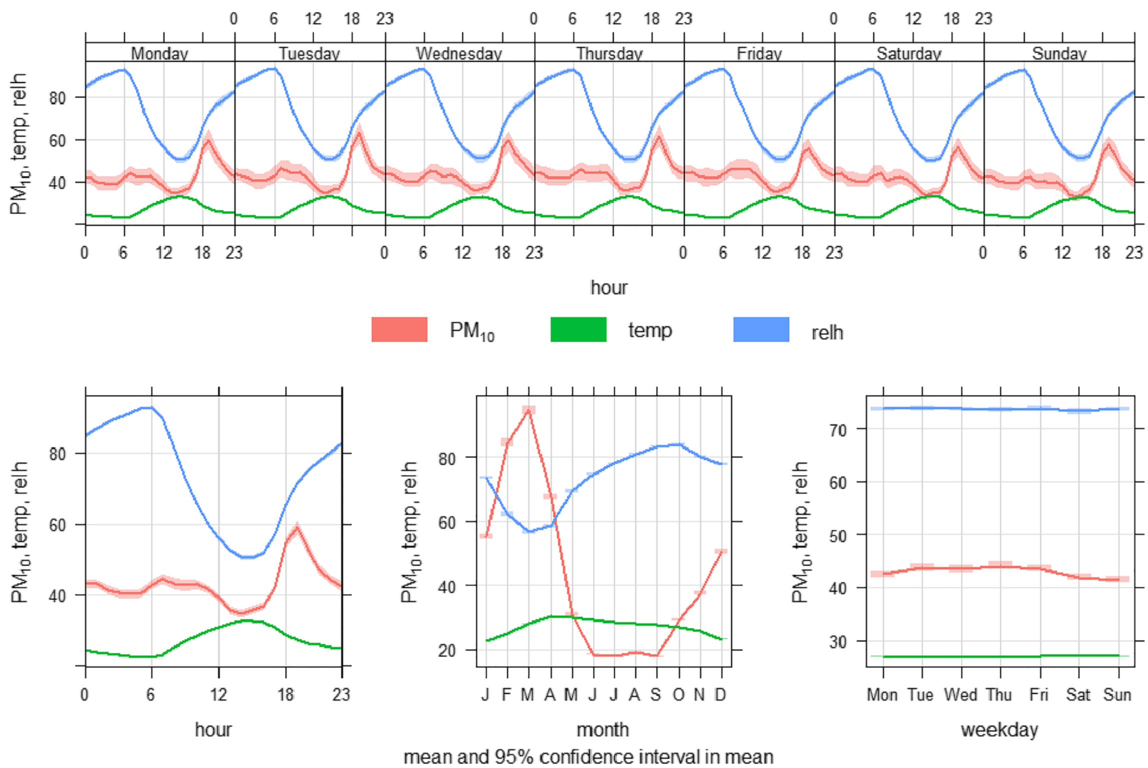


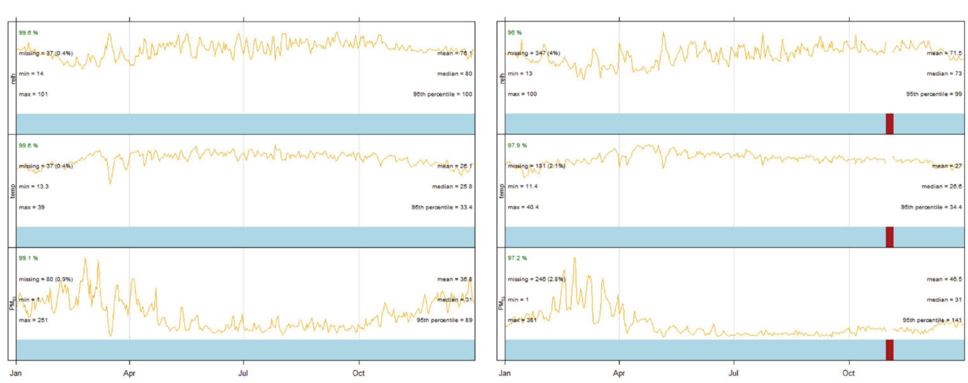
Fig. 4 Hourly, monthly, and weekday mean PM_{10} concentrations (μg/m^3), temperature (°C) and relative humidity (%) with 95% CI in Lamphun Province (2009–2017)

In Table 4 exhibits the correlation of PM_{10} and gaseous pollutants in different seasons from 2009 to 2017; the influencing pollutants of PM_{10} levels were CO and NO_2 throughout the year. The correlation was higher in summer and winter. O_3 concentrations were considered the main influencing factor on PM_{10} levels in winter after 2011. The four gases indicated no obvious difference in rainy season during the study period.

Models established

MLR was used as the simple statistical analysis for a predictive model for PM_{10} concentration. The independent variables consisted of two categories, namely, (i) pollutant group and (ii) climatologic parameters. The models were categorized in three models classified by season (summer, rainy and winter). The developed models, coefficient of determination (R^2), variance inflation factor (VIF) and Durbin Watson (DW) of each model are illustrated in Table 5. The developed model for summer and winter seasons provided a better model when compared with that of the rainy season model because the coefficients of determination were 0.63 for both summer and winter, whereas R^2 was 0.62 for the rainy season model. Moreover, the VIF of all models were lower than 5 and DW values were lower than 4. The DW statistic was used to test

Fig. 5 Relative humidity, temperature and PM_{10} concentration of year 2011 (**a**) and 2012 (**b**)



(a) 2011 (b) 2012

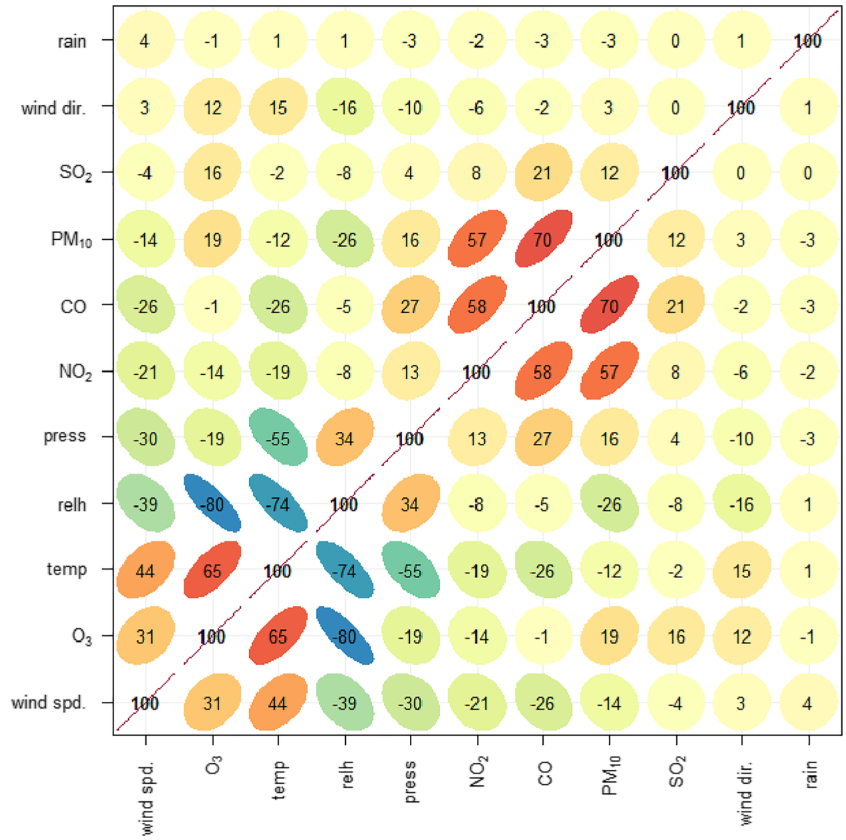


Fig. 6 Pearson correlation of climate factors and other pollutants with PM_{10} concentration

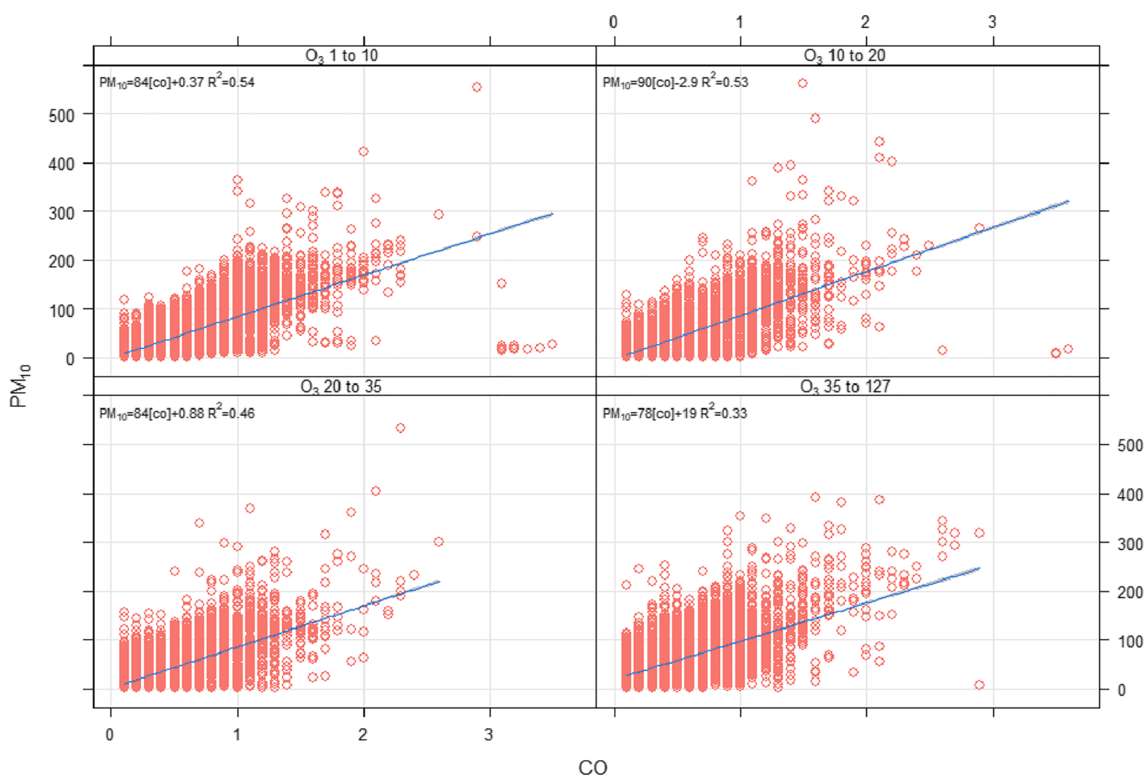


Fig. 7 Scatter plot of hourly PM_{10} vs. CO in Lamphun province stadium by different levels of O_3

Table 4 The correlations of difference season in the Lamphun monitoring station between 2009 and 2017

Year	Season	r (PM_{10}, SO_2)	r (PM_{10}, NO_2)	r (PM_{10}, CO)	r (PM_{10}, O_3)
2009	Summer	–	–	–	–
	Rainy	−0.037	0.366**	0.355**	0.217 **
	Winter	−0.047	0.750**	0.714**	0.284
2010	Summer	0.350**	0.708**	0.931**	0.354**
	Rainy	−0.075	−0.038	0.262**	0.500**
	Winter	−0.063	0.340**	−0.246	0.087
2011	Summer	0.316**	0.744**	0.883**	0.412**
	Rainy	−0.147	0.488**	0.238**	0.018
	Winter	0.616**	0.556**	0.808**	−0.009
2012	Summer	0.555**	0.834**	0.974**	0.536**
	Rainy	0.105	0.258**	0.393**	0.373**
	Winter	−0.216	0.656**	0.884**	0.548**
2013	Summer	0.126	0.441**	0.951**	0.448**
	Rainy	−0.277	0.380**	0.276**	0.263**
	Winter	0.302**	0.461**	0.846**	0.679**
2014	Summer	0.281**	0.777**	0.886**	0.368**
	Rainy	−0.104	0.388**	0.360**	0.467**
	Winter	0.225**	0.787**	0.690**	0.349**
2015	Summer	0.309**	0.819**	0.834**	0.203**
	Rainy	0.578**	0.268**	0.374**	−0.222
	Winter	−0.056	0.801**	0.388**	0.827**
2016	Summer	0.190	0.593**	0.670**	−0.195
	Rainy	−0.057	0.335**	0.291**	0.059
	Winter	0.306**	0.644**	0.065**	0.556**
2017	Summer	0.216**	0.766**	0.270**	0.537**
	Rainy	−0.041	0.306**	0.385**	0.042
	Winter	−0.061	0.746**	–	0.493**

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

autocorrelation in the residuals from the statistical regression analysis. The DW statistics for all models were lower than 2 indicating a positive autocorrelation. The VIF was used to estimate how much the variance of a regression coefficient was inflated due to multicollinearity in the model. The VIF values in summer, rainy and winter were moderately correlated with values ranging from 1.24–2.11, 1.16–1.72 and 1.16–1.70, respectively. The scatter diagrams of PM_{10} concentration and predictive variables of the seasonal models classified by season are presented in Fig. 8.

Seasonal variation of PM_{10}

PM_{10} concentration was analyzed to determine the AQI equivalent using the values indicated in the USEPA method (USEPA., 1999). The PM_{10} concentration was converted to AQI using the equivalent PM_{10} concentration and AQI according to the USEPA approach as illustrated in Table 6. The variation of PM_{10} concentration, illustrated in Fig. 9 in terms of the pollution calendar, indicated that high concentrations were regularly found during the dry season from January to April similar to the study of Yen [28]. The unhealthy

Table 5 Model summary for PM_{10} concentration forecasting during haze episode in northern Thailand

Prediction parameter	Model	R^2	VIF	DW
Summer	$PM_{10} = 131.97 + 55.21*CO + 0.80*NO_2–3.54*SO_2 + 1.14*O_3–1.84*Temp-1.26*RH-9.03*WS$	0.62	1.24–2.11	0.54
Rainy	$PM_{10} = 101.99 + 22.41*CO + 2.30*NO_2 + 1.07*SO_2 + 0.349O_3–0.89*RH-10.49*WS$	0.62	1.16–1.72	0.54
Winter	$PM_{10} = 102.27 + 22.32*CO + 2.29*NO_2 + 1.07*SO_2 + 0.49*O_3–0.91*Temp-0.86*RH-10.48*WS$	0.62	1.54–1.76	0.54

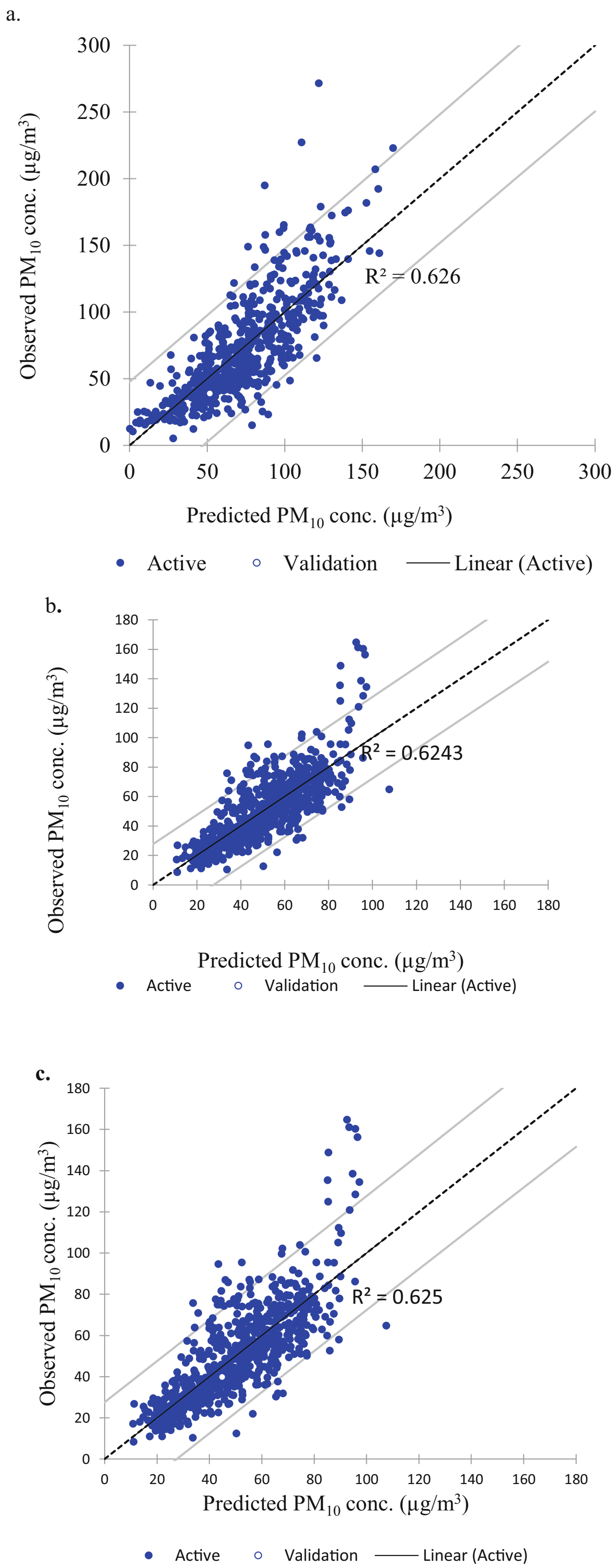


Fig. 8 Scatter plot of predicted PM_{10} concentration (µg/m^3) against observed PM_{10} concentration (µg/m^3) for **a** PM_{10}, Summer season, **b** PM_{10}, Rainy season, and **c** PM_{10}, Winter season

conditions when the average PM_{10} concentration of 24 h exceeded 154 microgram per cubic meter was detected yearly. The year variation was also detected, as the PM_{10} concentration in 2011 was lower than other years. The reasons for lower concentration detection were related to precipitation and relative humidity. For example, because of the devastating flooding in 2011, the number of dates exceeding 100 AQI was lower as illustrated in the PM_{10} concentration calendar shown in Fig. 9. Regarding PCD guidelines, the air quality presents both AQI and the common pollutants, namely, CO, O_3, PM_{10}, SO_2 and NO_2. In addition, AQI was always presented with a description for the general population. High concentrations of PM_{10} during the dry season (January to April) were confirmed by related studies [29–31]. During this period biomass is burned in agricultural areas and forest fires occur in upper northern Thailand [28].

Discussion

The goal of the study was to identify favorable meteorological conditions for high PM_{10} concentrations in Lamphun Province, upper northern Thailand. The regular dry season in the Southeast Asian region is usually characterized by intense burning activities, resulting in haze being transported to neighboring countries by prevailing winds and generally dry weather conditions across the region [29, 30, 32]. The result of this study indicated that the weekly PM_{10} concentration varied and decreased in 2011 due to flooding in most areas of Thailand including Lamphun Province. Precipitation during this year was slightly high compared with other years as presented in Fig. 10. Annual precipitation in 2011 in Lamphun was 1.8 and 1.5 times that of 2012 and 2013, respectively. Concerning the haze period during March and April, rainfall volume in March was 73.5 mm or 8.5 times that of 2012 and 5.7 times that of 2013. Similar to April, rainfall reached 156.7 mm in 2011 or 24 times that of 2012. Furthermore, the relative humidity in this year was also high that might have captured suspended particles in the air as indicated in the previous study [28]. In addition, the inversion phenomena might have been the cause of high PM concentration as indicated by Soheila Rezaei et al. in Tehran, Iran, where PM concentration during inversion days was higher than regular days [33]. The consequence of increasing relative humidity resulted in decreasing PM_{10} concentration in this year. High concentration of PM_{10} was always found in the afternoon daily, so the result of this study could be distributed to related organizations in the health sector to warn vulnerable groups to avoid spending time in the open air during the haze episode (February to March). Personal protective equipment such as masks should be used in case they could not avoid exposure. Concerning $PM_{2.5}$ concentration, the proportion of $PM_{2.5}$/PM_{10} was approximately 50% (0.50–0.56) from

Table 6 AQI (Air Quality Index) break point

AQI	PM_{10} 24 h. (μg/m^3)	O_3 1 h. (ppm)	SO_2 1 h. (ppb)	NO_2 1 h. (ppb)	Category
0–50	0–54	–	0.-35	0–53	Good
51–100	55–154	–	36–75	54–100	Moderate
101–150	155–254	0.125–0.164	76–185	101–360	Unhealthy for Sensitive Group
151–200	255–354	0.165–0.204	186–304	361–649	Unhealthy
201–300	355–424	0.205–0.404	305–604	650–1249	Very Unhealthy
301–400	424–504	0.405–0.504	605–804	1250-1649	Hazardous
401–500	505–604	0.505–0.604	805–1004	1650-2049	Very hazardous

Source: US.EPA [20]

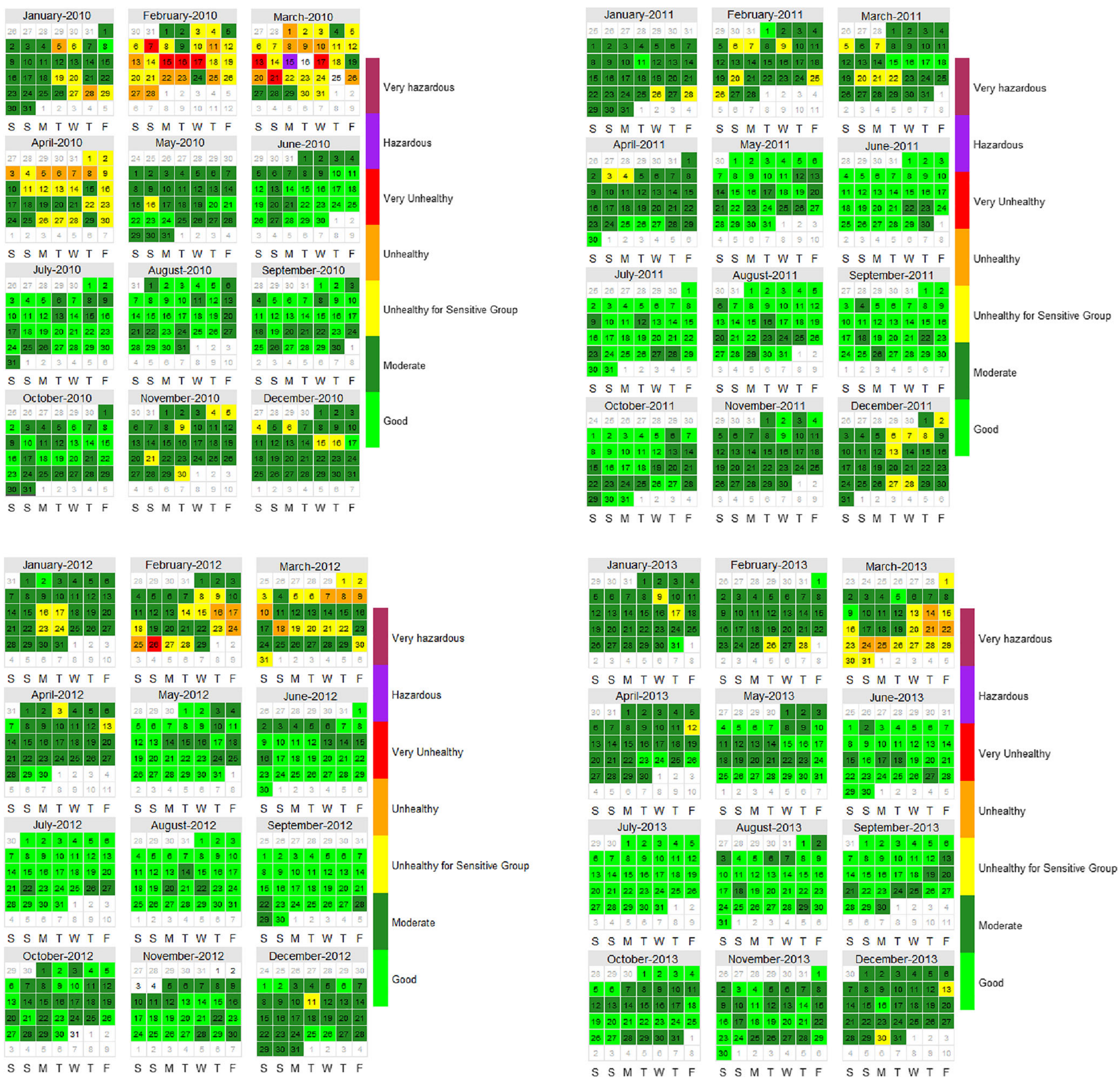


Fig. 9 PM_{10} concentration calendar in Lumphun Province for year 2010, 2011, 2012 and 2013

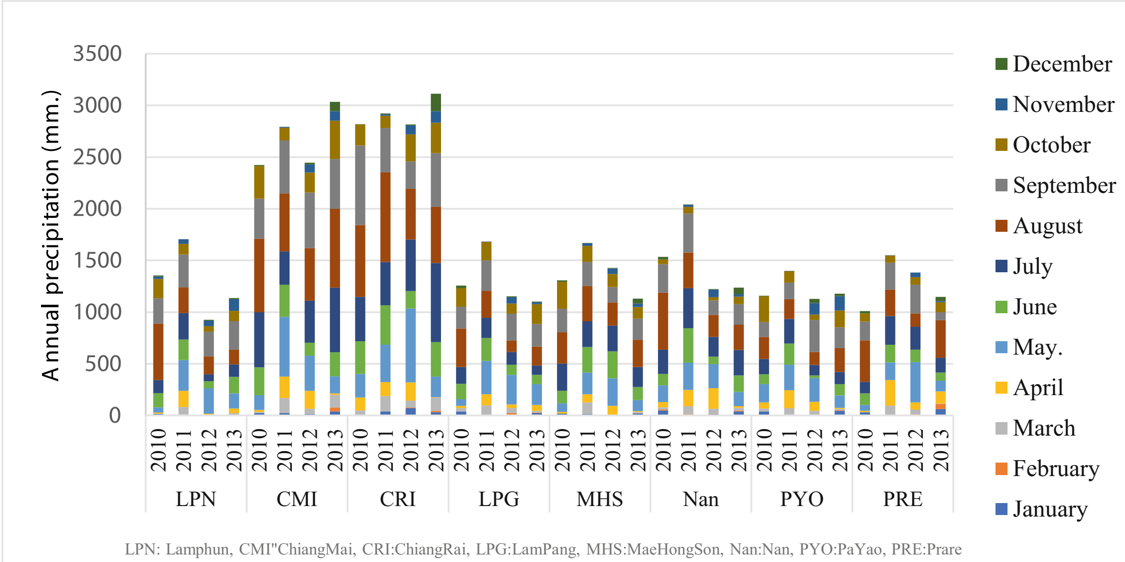


Fig. 10 Monthly Annual Rainfall in the upper north provinces of Thailand (2010–2013)

measurements in both urban and rural areas of Lamphun Province. This proportion was slightly higher than that reported in the study in Bangkok and Pathum Thani Provinces, which was only 0.34–0.52 [34]. When considering the measured PM_{10} concentrations from 2009 to 2017, $PM_{2.5}$ concentration would be high when using 0.5 fractions. For example, during the haze episode, the maximum was detected at 554 μg/m^3; therefore, the estimated $PM_{2.5}$ would be 277 μg/m^3. This value would be approximately 5 times that of the standard concentration announced by the PCD (24 h of 50 μg/m^3). $PM_{2.5}$ is a significant air pollutant impacting health. When the ratio of $PM_{2.5}/PM_{10}$ is over 0.5, the potential for high $PM_{2.5}$ concentration might be detected. The $PM_{2.5}$ measurement should be investigated in this province to obtain data to improve management and well-being of citizens and tourists.

Pearson's correlation coefficient indicated significant correlations between air pollutants (PM_{10}) and meteorological factors (relative humidity, temperature, pressure and wind speed), similar to the study of other researchers are shown in Table 7. The high correlation of PM_{10} and CO concentration were found during the study period with a correlation coefficient value of 0.79. The CO concentration always occurred when biomass materials did not burn completely. The potential sources of CO concentration in Lamphun Province might be induced from various activities generating incomplete combustion, namely, residue burning after the harvesting period from agricultural areas, forest fire, fossil fuel combustion from vehicles, and others. To clearly determine the sources of PM_{10} and CO, further analysis of particulate contents such as polycyclic aromatic hydrocarbons (PAHs) should be investigated. Measuring PAHs in particulate might show different components that could explain the sources. Substantially different correlations between air pollutants and meteorological parameters were observed given the vastly different meteorological conditions. Wind speed was reversely correlated with

Table 7 Correlations (r) values of PM_{10} and meteorological parameters at several stations in this study and other studies

Air pollutants	Locations/Stations	Temp	RH	WS	PS	References
PM_{10}	Lamphun (63 t)	−0.12	−0.26	−0.14	0.16	This study
PM_{10}	MaeHongSon, Thailand	0.07	−0.37	0.03	0.09	[31]
PM_{10}	Johor Bahru, Malaysia	0.16	−0.30	−0.11	–	[42]
PM_{10}	Beijing, China (summer)	−0.06	0.52	0.16	–	[35]
PM_{10}	Shanghai, China (summer)	−0.16	−0.33	−0.58	–	[35]
PM_{10}	Guangzhou, China (summer)	0.48	−0.46	−0.42	–	[35]
PM_{10}	Klang Valley, Malaysia	0.65	−0.41	0.32	–	[43]
PM_{10}	Zonguldak,Turkey (Summer)	0.28	−0.10	0.04	−0.52	[44]
PM_{10}	Kathmandu Valley, Nepal	−0.36	−0.54	0.16	0.24	[45]
PM_{10}	Ahmedabad, India (2008)	−0.34	−0.44	−0.17	–	[46]
$PM_{2.5}$	Karaj, Iran	0.05	0.21	–	0.24	[47]

air pollutants such PM_{10}, NO_2 and CO whereas temperature was positively related to O_3, indicating the important role of horizontal wind in pollutant dispersion and the important role of temperature in O_3 generating photochemical reactions [35–37]. Table 4 clearly shows that the Lamphun monitoring station revealed totally different major seasonal influencing factors. Therefore, investigating the spatial characteristics on a dynamic basis is needed. The occurrence of seasonal monitoring indicates the influencing factors in individual areas to better characterize their significance. In this way, pollution could be more efficiently controlled. In general CO and NO_2 affected PM_{10} concentrations [38, 39] more than SO_2. Concerning the developed models in three seasons, the pressure was excluded as the appropriate models for PM10 prediction in three seasons with the same coefficient of determination (0.62). The pressure was not significant in all seasons since the range of pressure in Thailand was not much changed during the study period. The VIF values varied from 1.16–1.95 that were lower than 10 that indicated there were no multi-collinearity between the independent variables. In addition, the values of DW were in 0.54 for all seasons indicated that the developed models did not face any first order problem [5, 40, 41].

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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