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Hospital out-and-in-patients as Functions of Trace Gaseous Species and Other Meteorological Parameters in Chiang-Mai, Thailand

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ABSTRACT

The aims of this study were to investigate the impact of meteorological parameters and trace gas concentrations on daily hospital walk-ins and admissions in Chiang-Mai province, Thailand, during 2007–2013. Advanced statistical models, including *t*-tests, Analysis of Variance (ANOVA), Multiple Linear Regression Analysis (MLRA) and Incremental Lifetime Particulate Matter Exposure (*ILPE*), were constructed using meteorological data from the Pollution Control Department (PCD), Ministry of Natural Resources and Environment (MNRE), Thailand, and the Thai Meteorological Department at Chiang-Mai Province Air Quality Observatory Site (TMCS) as well as the number of walk-in and admitted patients at Nakornping Hospital, Chiang-Mai (NHCM). The results showed that all trace gaseous species and PM_{10} were significantly higher during the "*haze episode*" than during the "*non-haze period.*" The FTIR spectra highlight the relatively homogeneous organic functional compositions of $PM_{2.5}$ collected from urban, suburban and rural observatory sites, indicating that agricultural waste burning plays an important role in air quality during the "*haze episode.*" The effect of age on susceptibility to respiratory diseases was investigated by separating the dataset into four groups (i.e., < 15 years, 15–59 years, 60–74 years and ≥ 75 years). The ANOVA results revealed a significant increase in hospital walk-ins and admissions for both genders in the < 15 years group ($p < 0.005$). MLRA revealed the significantly highest impacts of CO on hospital walk-ins for both genders. The predicted *ILPE* of PM_{10} showed the highest values for both genders during the "*haze-episode*" in 2007, with average values of 3.338 ± 0.576 g and 1.838 ± 0.317 g for male and female outdoor workers, respectively, over an exposure duration of 25 years.

Keywords: Trace gaseous species; Hospital admission; Chiang-Mai; FTIR; Incremental lifetime exposure.

INTRODUCTION

Several empirical studies highlight the association of nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2) and carbon monoxide (CO) with adverse short-term effects, including increases in daily mortality, particularly cardiorespiratory mortality, and morbidity (Kan *et al.*, 2010; Sousa *et al.*, 2012; Zhang *et al.*, 2013). NO_2 and O_3 have been observed to influence principally respiratory outcomes, while CO predominantly affects the cardiac system (Katsouyanni *et al.*, 2011). Recently, in Thailand, agricultural production and the use of private vehicles have dramatically increased. Previous studies indicate that overall private vehicle ownerships in Thailand increase as the income levels grow; after personal income reaches a certain level, people will shift from motorcycle to car ownership for prestige, convenience, comfort and safety (Pongthanaisawan and Sorapipatana, 2010). The emergence of contract farming as an institution for facilitating market exchange appears to have played a major role in Thailand for decades (Sriboonchitta and Wiboonpoongse, 2008). These phenomena caused several subsequent air pollution problems, as imperfect combustion of rotten agricultural waste biomass and traffic exhaust produced trace gaseous species, carcinogenic polycyclic aromatic hydrocarbons, carbonaceous aerosols and mutagenic particles ((Pongpiachan *et al.*, 2009; Pongpiachan, 2013a, b; Pongpiachan *et al.*, 2013a, b). Without exception, the largest and most culturally significant city in northern Thailand, Chiang-Mai, has experienced the worst air pollution during the past few years. During the haze episode in March 2013, the weekly average $PM_{2.5}$ levels in Chiang-Mai were between 2.8 and 7 times higher than the World Health Organization's (WHO) recommended 24 hour average concentration (Pongpiachan *et al.*, 2013c).

Numerous studies have found an intimate relationship between hospital admissions and meteorological parameters, such as outdoor temperature, atmospheric concentration of fine particles and trace gaseous species in different cities

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around the world (Cengiz and Terzi, 2012; Szponar *et al.*, 2012; Le *et al.*, 2013; Wang *et al.*, 2013; Yap *et al.*, 2013). In spite of various reports associated with ecological analysis of the epidemiological study using ambient PM data/ meteorological parameters obtained from the air quality station and fixed sites, there are limited numbers of studies focusing on the impacts of haze on hospital admissions (Emmanuel, 2000; Xie *et al.*, 2014; Zhang *et al.*, 2014). Furthermore, many factors such as gender, age, and gaseous species can affect patient's sensitivities to respiratory diseases (Bernas *et al.*, 2012; Romieu *et al.*, 2012; Szponar *et al.*, 2012; Gambhir *et al.*, 2013; Kurt *et al.*, 2013). During the past decades, numerous studies have been highlighted the association between haze and multiple respiratory hospitalizations in cities around the world (Bates and Sizto, 1987; Thurston *et al.*, 1994; Fung *et al.*, 2006). In order to assess the health risks associated with the occupational exposure to PM_{10} of outdoor workers close to air quality monitoring stations, the incremental lifetime particulate exposure (*ILPE*) were used in previous studies (Pongpiachan *et al.*, 2009, 2013a). In light of these facts, the principal aims of this study are to *i*) quantitatively identify meteorological factors and trace gaseous species affecting the number of out-patient department (OPD) and in-patient department (IPD) patients, *ii*) investigate the impacts of gender and age on numbers of OPD and IPD due to respiratory diseases, *iii*) use a multiple linear regression analysis (MLRA) to explore the association between hospital admissions and atmospheric parameters coupled with trace gaseous contents and *iv*) assess the impact of the "*haze episode*" on enhancement of *ILPE* of PM_{10} from 2007 to 2013 in Chiang-Mai, Thailand.

MATERIALS AND METHODS

A retrospective ecological study was conducted using meteorological parameters (i.e., outdoor temperature (*T*), relative humidity (*RH*), wind speed (*WS*), wind direction (*WD*), daily precipitation (*P*) and concentrations of particulate matter measuring ≤ 10 µm (PM_{10})) and trace gaseous species were provided by the Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand. Monitoring of particulate matter measuring ≤ 2.5 µm ($PM_{2.5}$) was conducted at three locations during two time periods. *Campaign I* involved sampling during the "*haze episode*" that occurred in the winter of 2011 (from March 20 to April 18, 2011); *campaign Π* was conducted in March 2013 (March 2 to March 31, 2012). Both campaigns were performed at three sampling sites: Yupparaj School Observatory Site (YOS; 18.791667°N, 98.988611°E), Thanasan Mansion Observatory Site (TOS; 18.807386°N, 98.985743°E) and Chiang-Mai Provincial Hall Observatory Site (CHOS; 18.836967°N, 98.970833°E) (see Fig. 1). YOS represents urban background samples, which were taken inside Yupparaj School campus located at the city center of Chiang-Mai adjacent to two major roads, Prapokklao Road and Ratchawithi Road. TOS is situated at the north of YOS in residential and business zones and thus reflects the air quality in the suburban area. TOS and YOS are located ~2.5 km apart from each other. CHOS is positioned at the northwest of YOS in the countryside and hence represents rural background samples.

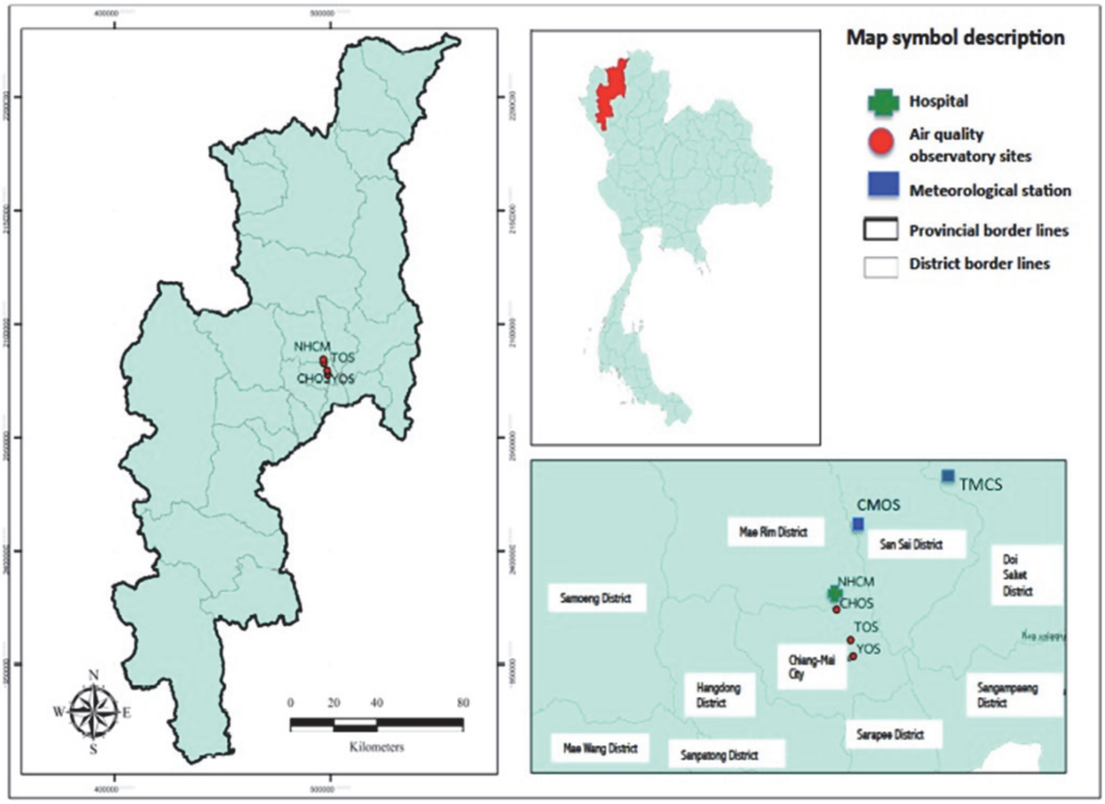


Fig. 1. Map of air quality observatory sites, a hospital and a meteorological station in Chiang-Mai province.

CHOS is located ~5 km and ~8 km apart from TOS and YOS, respectively. There were no obstructions in the vicinity of the sampling equipment, which was strategically positioned to be accessible to winds from all directions.

MiniVol™ portable air samplers (Airmetrics) were used to collect $PM_{2.5}$ for 24 h at three sampling sites. The MiniVol's pump draws air at 5 L/min through a particle size separator (impactor) and then through 47 mm Whatman quartz fiber filters (QFFs). The 2.5 micron particle separation is achieved by impaction. Quality assurance (QA) and quality control (QC) of $PM_{2.5}$ sampling were conducted according to particulate matter ($PM_{2.5}$) speciation guidelines, US-EPA (1999a). A Thermo Andersen PM_{10} High Volume Air Sampler (HVAS) was used to collect PM_{10} based on the compendium method IO-2.1 of US-EPA (1999b). The monitoring of PM_{10} and other trace gaseous species was conducted from January 1, 2007 to April 30, 2013 at the Thai Meteorological Department at Chiang-Mai Province Air Quality Observatory Site (TMCS), which is situated inside the campus of Maejo University (MU). It is worth mentioning that MU is located northeasterly 8 km away of Chiang-Mai city center (i.e., Three Kings Monument). Data on the number of male walk-in patients (Male-OPD), number of female walk-in patients (Female-OPD), number of admitted male patients (Male-IPD), and number of admitted female patients (Female-IPD) were collected for causes that were coded in the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (WHO, 2010). For instance, the selected patients should have diseases and/or symptoms of acute/chronic rheumatic fever, hypertensive diseases, heart diseases, cerebrovascular diseases, diseases of arteries, arterioles and capillaries, diseases of veins, lymphatic vessels and lymph nodes, other and unspecified disorders of the circulatory system coupled with acute upper respiratory infections, influenza and pneumonia, acute lower respiratory infections as classified in ICD-10-CM Codes (WHO, 2010). It is also important to note that only general populations were used in this study. All analyses were performed according to gender and age group (< 15 years, 15–59 years, 60–74 years and ≥ 75 years), as previously described by Chan *et al.* (2013). In addition, the number of hospital admissions was recorded from January 1, 2007 to April 30, 2013 at Nakornping Hospital, Chiang-Mai (NHCM). Since the majority of patients receiving medical services at NHCM are residents in Chiang-Mai city and TOS, YOS, CHOS, and TMSC are air quality observatory sites located adjacent to NHCM within a 10 km radius, it is therefore rationale to conduct the exposure assessment approach by using information from the weather stations as mentioned above.

Time Series Approach

Autocorrelation plot (Box and Jenkins) is a widely employed model for evaluating randomness in a data set and thus can be applied to investigate the randomness of OPD and IPD with time. This randomness can be determined by calculating autocorrelations for data values at different time lags. In the case of random, such autocorrelations should theoretically be close to zero for any and all time-lag intervals. In the case of non-random, one or more of the autocorrelations will be significantly non-zero. Autocorrelation plots can be conducted as follows. Firstly, vertical axis represents autocorrelation coefficient, which can be calculated by using the Eq. (1).

$$R_h = \frac{C_h}{C_0} \tag{1}$$

where R_h is autocorrelation coefficient of patient number (i.e., Male-IPD, Female-IPD, Male-OPD, and Female-OPD) and ranges between –1 and +1. Note that C_h is autocovariance function, which can be described in Eq.2.

$$C_h = \frac{1}{N}\sum_{t=1}^{N-h}(Y_t - \overline{Y})(Y_{t+h} - \overline{Y}) \tag{2}$$

where N, t, h, Y_t, $\overline{Y}$, Y_{t+h}, stand for total number of patients, time, time lag, number of patients at time t, average of patient numbers, and number of patients at time $t + h$, respectively. In addition, C_0 is the variance function, which can be written as follows:

$$C_0 = \frac{\sum_{t=1}^{N}(Y_t - \overline{Y})^2}{N} \tag{3}$$

Secondly, horizontal axis represents time lag h ($h = 1, 2, 3, \ldots$). Thirdly, the confidence bands have fixed width that depends on sample size and can be calculated by using the following formula:

$$\pm\frac{Z_{1-\alpha/2}}{\sqrt{N}} \tag{4}$$

where N is the sample size, Z is the cumulative distribution function of the standard normal distribution and α is the significance level.

FTIR Analysis

In this study, IRAffinity-1 Shimadzu was used to analyze organic functional groups in $PM_{2.5}$. Subtraction of the blank (i.e., the spectrum of the empty QFFs) from the filter sample was performed for each QFFs. Each spectrum was determined by averaging 16 scans at a resolution of 2 cm^{-1}. The spectra describe the absorbance of radiation as a function of wavenumber in the region of 900–4000 cm^{-1}. For more details on quantification of identified functional groups in $PM_{2.5}$ samples collected on QFFs, please refer to a previous publication by Krost and McClenney (1994).

MLRA Assessment

MLRA was used to investigate the influence of independent variables (i.e., *T*, *WS*, *Sin(WD)*, *Cos(WD)*, CO, NO_x, SO_2, O_3) on a dependent variable (i.e., Male-OPD or Female-OPD). It is well known that weather conditions and air pollution levels play an important role in hospital admissions for respiratory diseases (Chan *et al.*, 2013; Martin *et al.*, 2013). To investigate the influence of trace gaseous concentrations and meteorological variables on hospital admissions for respiratory diseases, Male-OPD and Female-OPD were modeled as:

$$Male - OPD = a + bT + cWS + dSin(WD) + eCos(WD) + fCO + gNO_x + hSO_2 + O_3 \tag{5}$$

$$Female - OPD = a + bT + cWS + dSin(WD) + eCos(WD) + fCO + gNO_x + hSO_2 + O_3 \tag{6}$$

Multiple linear regressions can establish the relative predictive importance of the independent parameters on the dependent variables. The analyses were performed using the SPSS 13.0 software for Microsoft Windows with the 'stepwise' MLRA method.

General Population Exposure of Outdoor Activities to PM_{10} and $PM_{2.5}$

To assess the health risks associated with general population exposure to both PM_{10} and $PM_{2.5}$ during the outdoor activities, an *ILPE* model was employed and defined as:

$$ILPE = C \times IR \times t \times EF \times ED \tag{7}$$

ILPE = Incremental lifetime particulate matter exposure (g)
C = PM_{10} and $PM_{2.5}$ concentrations (μg/m^3)
IR = Inhalation rate (m^3/h)
t = Daily exposure time span (6 h/d, for two shifts)
EF = Exposure frequency (250 d/year [a], upper-bound value)
ED = Exposure duration (25 years [a], upper-bound value)
Note: [a] Adapted from Human Health Evaluation Manual (US EPA, 1991).

According to the methods for the calculation of inhalation dosimetry (US EPA, 1994), the inhalation rates of male and female outdoor activities were estimated as 0.89 and 0.49 m^3/h, respectively. The *ILPE* model was adapted from the probabilistic incremental lifetime cancer risk (*ILCR*) model, which was used to assess the exposure of traffic police to PAHs during their work time in China (Hu *et al.*, 2007).

RESULTS AND DISCUSSION

Trace gaseous species, meteorological parameters, numbers of Male-OPD, Female-OPD, Male-IPD and Female-IPD were identified successfully throughout the sampling campaign (n = 2,312). Table 1 summarizes the average concentrations of all air quality parameters measured at TMCS coupled with hospital admissions monitored at NHCM. To assess the impact of haze episodes on meteorological parameters and patient numbers, the data were separated into two groups: "*haze period*" and "*non-haze period*". Because March is the month with the most severe haze episodes in Chiang-Mai, data collected in March of each year from 2007 to 2013 were assigned to

Table 1. Statistical description of trace gaseous species, meteorological parameters, OPD and IPD patient numbers at Nakornping Hospital, Chiang-Mai province, 2007–2013.

	CO	NO_x	SO_2	O_3	PM_{10}	RH	P	WS	WD	T	Male-OPD	Female-OPD	Male-IPD	Female-IPD
Non-Haze Period (2007–2013)	0.450 ± 0.210	11.2 ± 5.97	2.86 ± 3.30	15.3 ± 10.4	34.7 ± 19.5	66.2 ± 19.5	3.27 ± 8.70	11.7 ± 4.68	208 ± 124	26.4 ± 2.82	47.8 ± 22.4	53.0 ± 25.1	5.18 ± 2.68	3.90 ± 2.29
Haze Period (2007–2013)	0.704 ± 0.272	16.3 ± 5.86	4.66 ± 5.97	18.6 ± 12.6	72.5 ± 26.2	55.9 ± 14.4	0.535 ± 2.57	11.4 ± 4.76	193 ± 71.8	27.1 ± 2.08	47.8 ± 20.2	54.1 ± 23.7	5.50 ± 2.53	4.41 ± 2.27
t-Test ($p < 0.05$)	S	S	S	S	S	S	S	NS	S	S	NS	NS	NS	S

CO: Carbon monoxide [ppm], NO_x: Nitrogen oxides [ppb], SO_2: Sulfur dioxide [ppb], O_3: Ozone [ppb], PM_{10}: Particulate Matter of 10 Microns in diameter or smaller, RH: Relative humidity [%], P: Daily Precipitation [cm], WS: Wind speed [m/s], WD: Wind direction, T: Temperature [°C], Male-OPD: Number of male walk-in patients, Female-OPD: Number of female walk-in patients, Male-IPD: Number of admitted male patients, Female-IPD: Number of admitted female patients, S: Significant, NS: Not Significant.

the "*haze period*" and data collected from January 1, 2007 to April 30, 2013, excluding March data, to the "*non-haze period*". The atmospheric concentrations of $PM_{10\text{-“haze period”}}$ varied from N.D. to 128 µg/m^3 with an average of 72.5 ± 26.2 µg/m^3, and the concentrations of $PM_{10\text{-“non-haze period”}}$ ranged from N.D. to 118 µg/m^3 with an average of 34.7 ± 19.5 µg/m^3. These two groups differ significantly in average PM_{10} concentrations based on the two-sample *t*-Test ($p < 0.05$). Statistical descriptions of OPD and IPD patient numbers at NHCM during 2007–2013 are displayed by gender and age in Table 2. The ANOVA results indicate some significant differences among age groups in OPD and IPD patient numbers. For instance, Male-OPD and Female-OPD show the highest values of 21.3 ± 10.9 ($p < 0.005$) and 27.8 ± 14.0 ($p < 0.005$) at age group 0–14 and age group 15–59, respectively. For the age group 0–14, Male-IPD and Female-IPD displayed the maximum values of 2.1 ± 1.8 and 1.5 ± 1.4, respectively.

The atmospheric concentrations of CO, NO_x, SO_2 and O_3 were assessed for the two periods. All trace gas concentrations detected during the haze episode were significantly higher than those of the *non-haze period,* as displayed in Table 1 ($p < 0.05$). However, it is interesting to note that there were no significant differences in Male-OPD, Female-OPD and Male-IPD between the two periods. There are several possible explanations for this finding. Firstly, respiratory disease encompasses pathological conditions affecting the organs and tissues in higher organisms, such as the upper respiratory tract, trachea, bronchi, bronchioles, alveoli, pleura and pleural cavity, which may subsequently lead to inflammatory lung disease, obstructive lung diseases, chronic obstructive pulmonary disease, respiratory tract infections, malignant tumors and pleural cavity diseases. As a consequence of complicated inhalation pathways, respiratory diseases can be caused by a variety of factors including, but not limited to, trace gaseous species. Secondly, some alterations in personal exposure as well as spatial variation of PM_{10} can dramatically deteriorate gender differences of hospital admissions. Thirdly, the level of physical exercise and type of activities (e.g., sleeping, sitting, light exercise and heavy exercise) can affect the particle deposition in the human lungs as estimated by using traffic-related particles (Oravisjärvi *et al.*, 2011). Fourthly, a previous study highlights the most evident health effect caused by multiple exposures to gases was upper respiratory track irritation, followed by the disruption of oxygen transport, and finally central nervous system disorders (Jumpponen *et al.*, 2013). In addition, there are some environmental exposures and other perplexing elements in individuals, which might have influenced the number of patients with respiratory diseases (Cruickshank *et al.*, 2014; Hong *et al.*, 2014).

It is also noteworthy that Female-IPD during the haze episode was significantly higher than during the non-haze period, indicating a high susceptibility of females to severe respiratory diseases associated with exposure to outdoor air pollution (see Table 1). The unusually high Female-OPD observed on July 15, 2009 (n = 254) was primarily due to acute upper respiratory infection, unspecified (J069), acute nasopharyngitis (J02), common cold (J0) and acute bronchitis (J20), with percentage contributions of 26.1%, 20.9%, 12.7% and 7.4%, respectively (see Fig. 2A). Although respiratory diseases can arise from numerous causes, including inhalation of toxic trace gaseous species, smoking habits and socioeconomic status, it seems reasonable to ascribe viral infections as the principal cause of the high Female-OPD found on July 15, 2009 during the rainy season (Cohen *et al.*, 2013; Etemadi *et al.*, 2013; Lai *et al.*, 2013).

Despite an extraordinary high Female-OPD found during the rainy season of 2009, the time series approach using autocorrelation plots show a relatively strong sinusoidal wave observed in Female-IPD (see Fig. 2B). This can be explained by relatively higher sensitivities of female patients on severe respiratory diseases in comparison with those of male patients. Similar variation patterns were observed in Male-OPD and Female-OPD but with higher amplitudes. It is important to note that the majority of R_h values of both genders are higher than confidence bands. This indicates a higher degree of impacts as may be influenced by other confounding factors (i.e., smoking habits, diets, and life style) rather than the periodic components. In the case of a truly random time series would show an autocorrelation function that drop suddenly from 1 at zero lag to near zero at lags equal to one or larger. Since all autocorrelation plots show sinusoidal wave patterns, it appears reasonable to conclude that the time series of all hospital admissions are not random.

For this study, the functional groups of organic and inorganic species existing in $PM_{2.5}$ aerosols were successfully identified using IRAffinity-1 Shimadzu FTIR spectroscopy.

Table 2. Statistical description of OPD and IPD patient numbers by gender and age at NHCP from 2007 to 2013.

Age Range	0–14		15–59		60–74		75+		F-Value	Statistical
(Years)	Aver	Stdev	Aver	Stdev	Aver	Stdev	Aver	Stdev	($p < 0.005$)	Significance
Male-OPD	21.3	10.9	18.7	9.5	6.1	4.2	3.5	2.7	3137	S
Female-OPD	17.3	8.8	27.8	14.0	5.8	4.2	3.7	2.9	3856	S
t-Value (p < 0.005)	13.7		–25.9		2.4		–2.4			
Statistical Significance	S		S		NS		NS			
Male-IPD	2.1	1.8	1.3	1.2	1.0	1.0	0.9	1.0	410	S
Female_IPD	1.5	1.4	0.80	0.92	0.78	0.92	0.86	1.0	237	S
t-Value (p < 0.005)	12.6		15.9		7.8		1.4			
Statistical Significance	S		S		S		NS			

Aver: Average, Stdev: Standard Deviation.

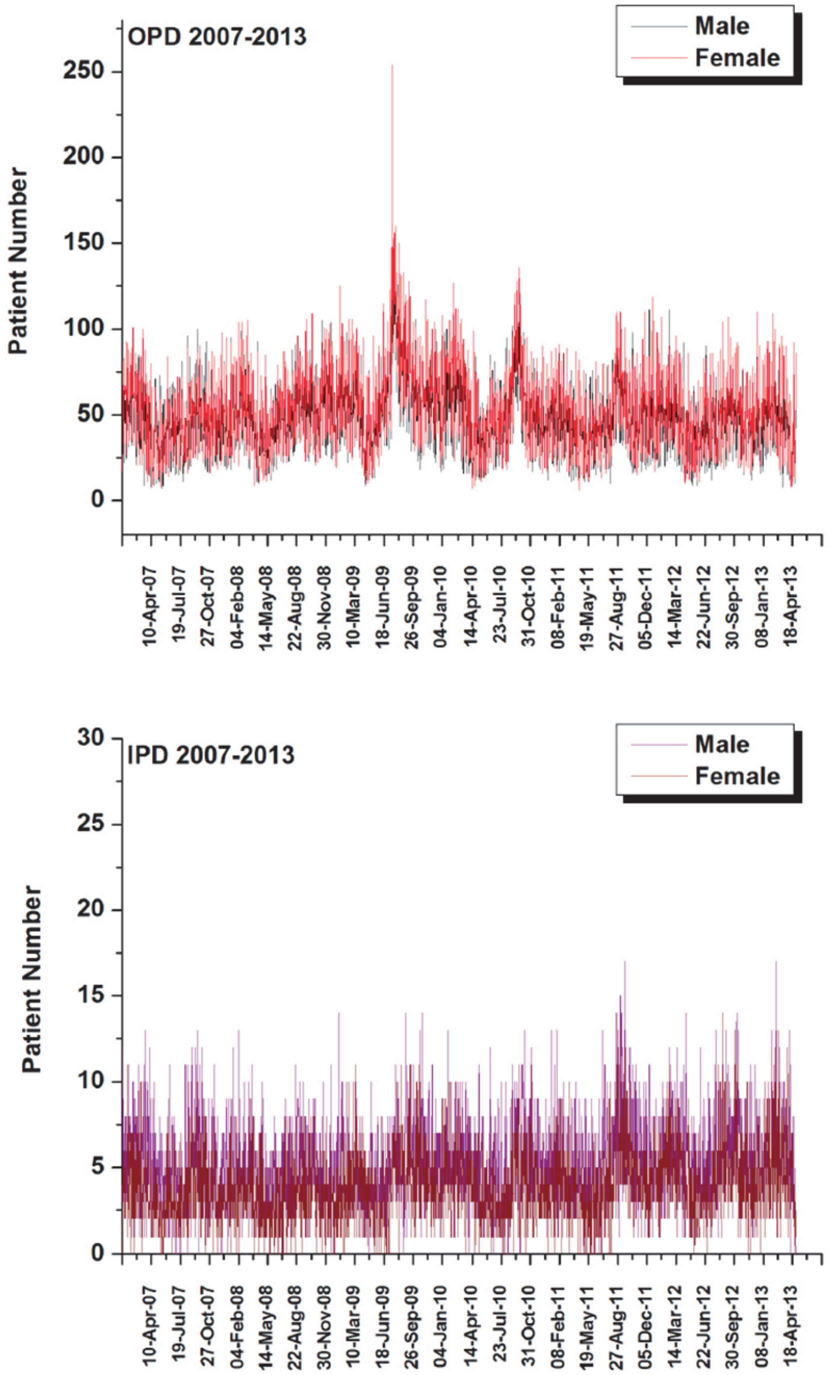


Fig. 2A. Variation in number of OPD and IPD patients from April 2007 to April 2013.

The monthly average FTIR spectra of $PM_{2.5}$ collected at YOS, TOS and CHOS from March 2 to March 31, 2012 are illustrated in Fig. 3. The IR absorption peaks of silicate from QFFs show distinct bands approximately 1000–1100 cm^{-1} and therefore interfere with the absorption peaks of $PM_{2.5}$ aerosol samples, which absorb in the same range. Overall, the spectra of all samples are generally moderately comparable to each other and can be categorized by *i*) three sharp and strong absorption bands in the 1000–1130 cm^{-1} intervals (Si-O-Si stretching), which may represent the absorption bands of QFFs; *ii*) the overlap of several possible absorption peaks, including free water, C-C stretching of aromatic and alkene double bonds, C = O stretching of secondary amides corresponding to NH, COO asymmetric stretching of metal carboxylates and carbonate minerals (calcite) in the interval from 1268 to 1756 cm^{-1}; and *iii*) the observation of aliphatic C-H bond absorption bands, which are the series of shared peaks from 2800–3000 cm^{-1}. Aliphatic carbon absorbance in aerosols shown at 2924 and 2958 cm^{-1} were assigned to CH_2 aliphatic carbon stretching absorptions, while CH_3 aliphatic carbon stretches were observed at 2850 cm^{-1} and *iv*) Alcohol absorption

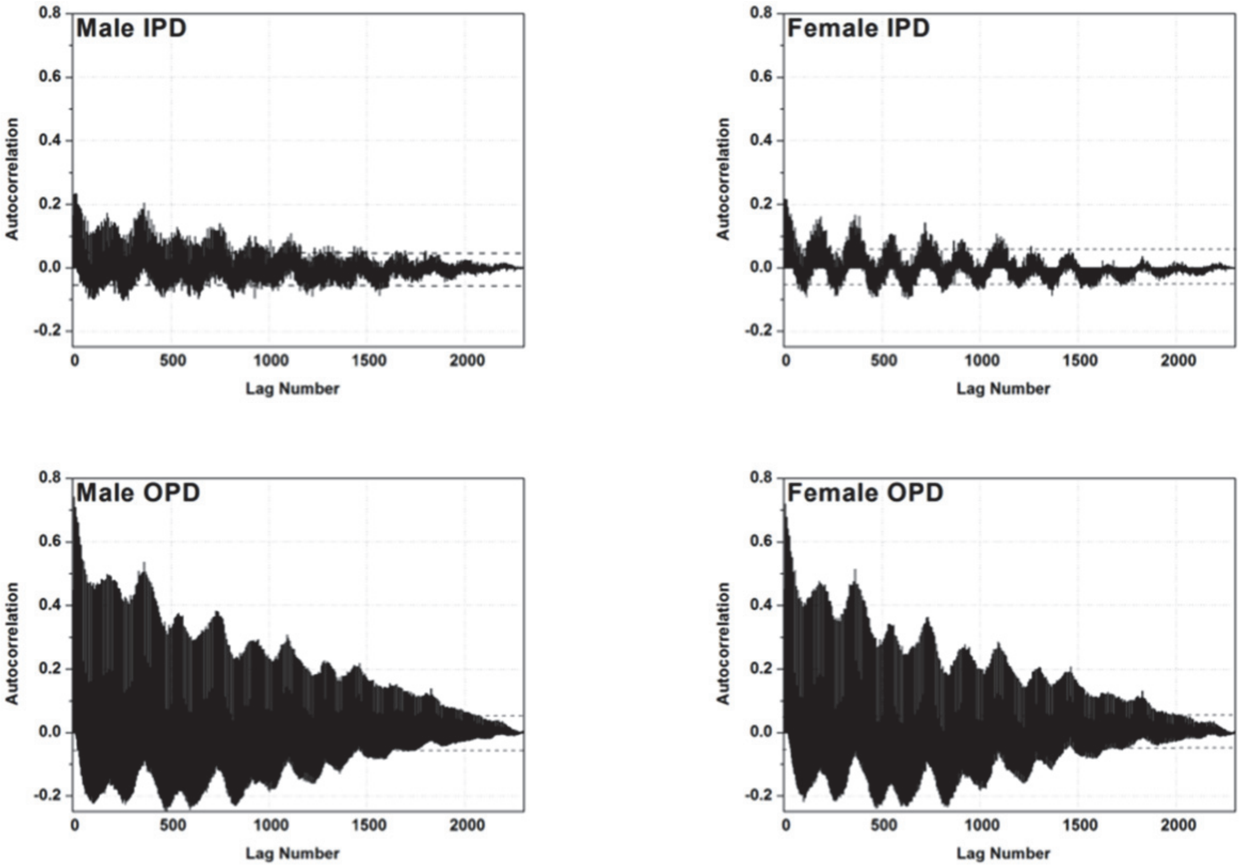


Fig. 2B. Plots of autocorrelation using number of OPD and IPD patients from April 2007 to April 2013.

bands were also shown at approximately 3250–3750 cm^{-1}. Despite some subtle differences in the vibrational modes of organic components, which highlight the differences in chemical compositions at each observatory site, the FTIR spectra of all sampling sites showed comparatively similar FTIR spectra characteristics in the frequency range from 900 to 4000 cm^{-1}. The results indicate that biomass burning may be the overwhelming provincial or regional-scale source of organic functional compositions in Thailand and a significant global source of organic species.

The predicted *ILPE* values of PM_{10} were significantly higher at CMOS-2007 in both genders after the "*haze episode,*" with average values of 3.338 ± 0.576 g for male and 1.838 ± 0.317 g for female for PM_{10} accumulated over an exposure duration of 25 years. This finding can be attributed to several causes. In addition to non-seasonal emission sources such as electric power plants, industrial factories, incinerators, domestic heating and vehicle exhaust, uncontrolled biomass burning in agricultural areas and neighboring mountain fires have been responsible for the increase in airborne particles during winter over the past several years (Pongpiachan *et al.*, 2013c). This phenomenon is further intensified by the "thermal inversion", which occurs predominantly during the cold period. The unique mountain topography of the Chiang-Mai province can also play a role in generating a thermal inversion because it can occasionally trigger cold airflow from mountain peaks down into valleys. This cold air then pushes under the warmer air rising from the valley, creating the inversion. The significantly lower *ILPE* of PM_{10} observed at CMOS-2012 (i.e., 2.171 ± 1.114 g for males and 1.195 ± 0.613 g for females) illustrates the consequences of proactive anti-burning and smog prevention activities of the local administration since November 2011. It is also worth mentioning that the 6 years averaged *ILPE* of PM_{10} during the "*haze episode*" is approximately 2.16 times higher than that of the "*non-haze episode*" for both genders.

Influences of Gender and Age on OPD and IPD Patient Numbers

Age-dependent differences in hospital admissions can have multiple contributory factors. Previous studies highlight that very young children have less immune protection than older children and adults, and thus are highly susceptible to influenza transmission (Gambhir *et al.*, 2013). Particular concerns with regard to the importance of secondhand smoke (SHS) on lower respiratory tract infection (LRTI) severity have been raised for infants with a familial atopic predisposition (Lemke *et al.*, 2013). Significant increased mortality risk from PM_{10} exposure was discovered in both Santiago (in infants and older children) and Mexico City (only in infants) (Romieu *et al.*, 2012). For O_3, an enhanced mortality risk was detected in Mexico City (in infants and older children) and in São Paulo (only in infants during the warm season) (Romieu *et al.*, 2012).

Independent *t*-Tests were used to investigate the

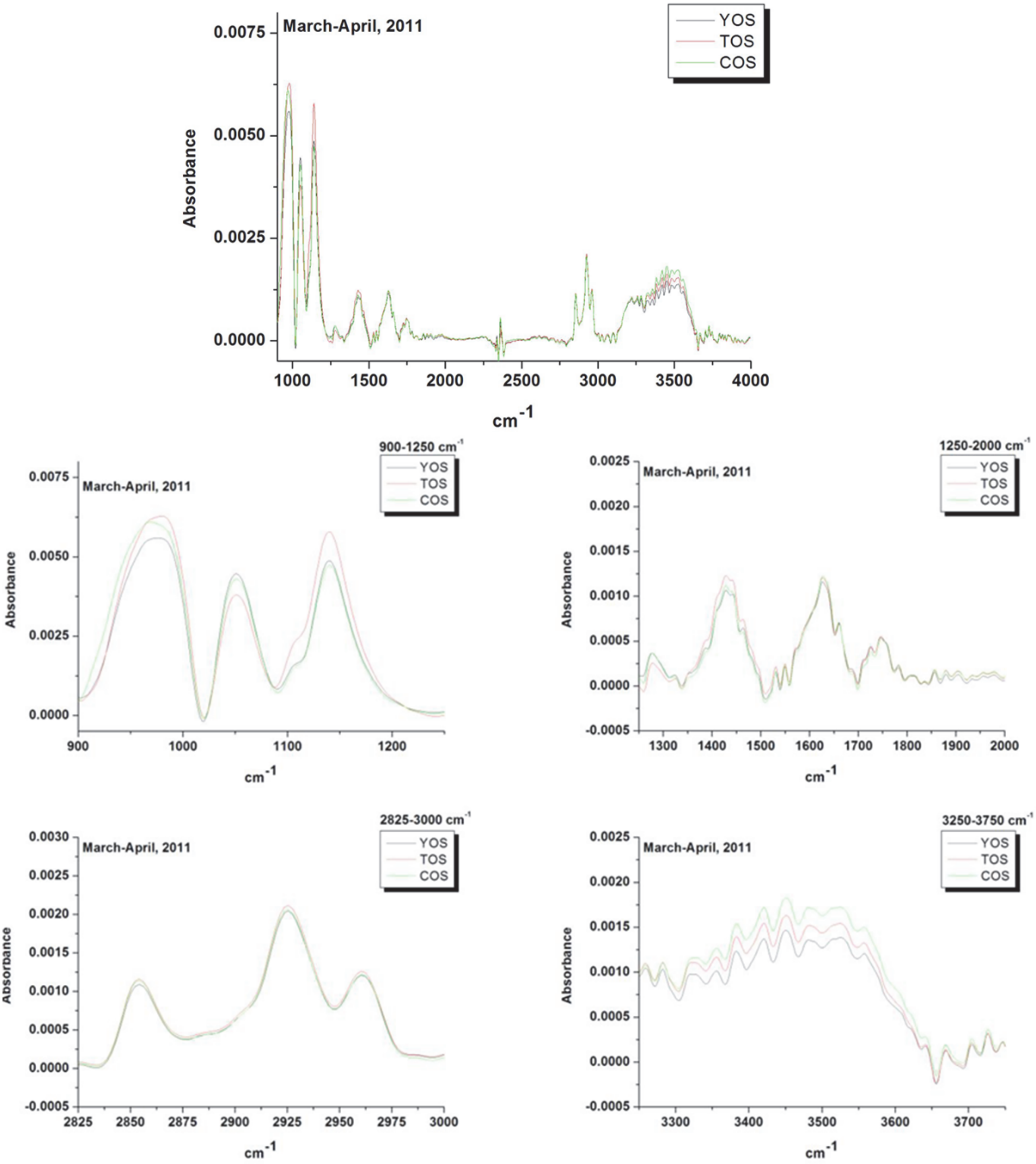


Fig. 3. A monthly average FTIR spectra of $PM_{2.5}$ collected at YOS, TOS and CHOS from March 2 to March 31, 2012.

influence of gender on hospital OPD and IPD admissions, as displayed in Table 2. Generally, there is some evidence to suggest that Male-IPD numbers were significantly higher than those of Female-IPD in the age groups of 0–14, 15–59 and 60–74. For age group 75+, there was no significant difference between Male-IPD and Female-IPD numbers. It is interesting to note that the independent *t*-Test results reveal a significant increase in Male-OPD in the 0–14 age group, while a significant decrease in Male-OPD was observed in the 15–59 age group. Similarly, there were no significant differences in Male-OPD and Female-OPD in the 60–74 and 75+ age groups. Overall, these results indicate significant susceptibility of both male and female children to respiratory diseases.

Several confounding factors may have contributed to the significantly higher hospital admissions of infants and adolescents in Chiang-Mai province. First, smoking prevalence among Thai adolescents between the ages of

13–17 has increased from 12.0% to 18.3%, depending on the study area (Sirirassamee and Sirirassamee, 2013). More than 70% of smokers reported that they smoked manufactured cigarettes (Sirirassamee and Sirirassamee, 2013). Secondly, a viral etiology of fever and respiratory tract infection syndrome was most prevalent among children aged < 4 years in Shaanxi province, which is consistent with the finding that both Male-IPD and Female-IPD are significantly higher in the 0–14 age group in Chiang-Mai province (Martin *et al.*, 2013). Third, an early study that concentrated on the effects of socioeconomic status (SES) suggests that $PM_{2.5}$-associated hospital admission rates for all respiratory outcomes were predominantly positive in children aged 1 to 9 years in 12 California counties, from 2000 to 2005, consistent with the exceptionally high hospital admissions of the 0–14 age group in Chiang-Mai for both genders (Yap *et al.*, 2013). Apart from these perplexing causes, there are some possible biological mechanisms, which can greatly affect to air pollution at the study site. Several studies highlight the impact of isoprene, monoterpene, and terpene biogenic emissions on ozone levels and a regional pollution episode (He *et al.*, 2000; Solmon *et al.*, 2004; Curci *et al.*, 2009). It is well known that isoprene and monoterpene fluxes are continuously released above different types of forest such as a mixed temperate forest (Laffineur *et al.*, 2011), eucalyptus forest (Trapp *et al.*, 2001), and hardwood forest (Pressley *et al.*, 2006).

Multiple Linear Regression Analysis (MLRA)

Table 3 and Table 4 summarize the regression coefficients obtained from Eqs. (5) and (6), respectively. In this study, PM_{10} data set was not included into the MLRA because (*i*) trace gaseous species tend to be more responsible for acute effects on hospital admissions than PM_{10}. For example, PM_{10} contributes to the enhancement of asthmatic hospitalization for only 1.82% while SO_2, NO_2 and BC on the concurrent day and previous day corresponded to 6.41%, 8.26% and 6.62% in Shanghai, China, respectively (Cai *et al.*, 2014), (*ii*) the most recent study highlights the stronger connection between $PM_{2.5}$ and hospital admissions in comparison with those of PM_{10} (Rodopoulou *et al.*, 2014). The independent variables selected in Eqs. (5) and 6 are assumed to be "independent". In fact, they may correlate with each other and have an "additive effect" on health outcome. For instance, the heterogeneous reaction of NO_2 with PAHs will lead to the formation of nitro-PAHs, which have been classified as mutagenic and carcinogenic agents, and continued concern due to their 200,000 times higher mutagenicity and 10 times higher carcinogenicity compared to PAHs (IARC, 1998; Bamford *et al.*, 2003). Some kinetics of the reactions of NO_2 with O_3 coupled with particle formation from homogeneous reactions of SO_2 and NO_2 can significantly alter the level of air pollutants and thus inevitably affect the hospitalizations (Cox, 1973; Cox and Coker, 1983).

A regression coefficient is the average amount that the dependent variable increases when the independent variable is increased by one unit and the other independent variables are held constant. Thus, the higher the coefficient, the

Table 3. Impact of meteorological parameters and trace gaseous species on Male-IPD at NHCP from 2007 to 2013, as assessed by MLRA.

	Unstandardized Coefficients		Standardized Coefficients	*t*-Value	Statistical Significance
	B	Std. Error	Beta		
(Constant)	56.845	2.613		21.754	0.000
T	–0.134	0.047	–0.075	–2.838	0.005
WS	–0.187	0.116	–0.038	–1.609	0.108
Sin (WD)	–0.826	0.838	–0.023	–0.986	0.324
Cos (WD)	0.259	0.768	0.008	0.338	0.736
CO	13.053	2.727	0.136	4.787	0.000
NO_x	–0.317	0.121	–0.080	–2.617	0.009
SO_2	–0.393	0.228	–0.062	–1.728	0.084
O_3	–0.251	0.063	–0.120	–4.002	0.000

Table 4. Impact of meteorological parameters and trace gaseous species on Female-IPD at NHCP from 2007 to 2013, as assessed by MLRA.

	Unstandardized Coefficients		Standardized Coefficients	*t*-Value	Statistical Significance
	B	Std. Error	Beta		
(Constant)	62.355	2.937		21.228	0.000
T	–0.161	0.053	–0.080	–3.033	0.002
WS	–0.295	0.130	–0.054	–2.265	0.024
Sin (WD)	–0.338	0.942	–0.008	–0.358	0.720
Cos (WD)	0.479	0.863	0.013	0.554	0.579
CO	17.251	3.065	0.160	5.628	0.000
NO_x	–0.282	0.136	–0.063	–2.073	0.038
SO_2	–0.461	0.256	–0.064	–1.802	0.072
O_3	–0.241	0.070	–0.102	–3.413	0.001

more influence there is on hospital admissions. β is the average amount the dependent variable increases when the independent variable is increased by one standard deviation and the other independent variables are held constant. Therefore, the β weights reflect the unique contribution of each of the independent variables to Male-OPD and Female-OPD.

As observed in Table 3, Male-OPD and Female-OPD had significant positive regression weights for CO, with unstandardized β values of 13.053 ($p < 0.000$) and 17.251 ($p < 0.000$), respectively, indicating that higher CO concentrations were associated with higher hospital admissions for both genders. This phenomenon is consistent with a previous study reporting that exposure to CO is a frequent cause of patient hospitalization in the Children's Clinical Hospital (DSK) (Szponar *et al.*, 2012). It is also worth mentioning that carbon monoxide intoxication remains a pressing health concern, particularly for children (Bernas *et al.*, 2012; Kurt *et al.*, 2013). In contrast, O_3 had negative influences on hospital admissions for both genders, as illustrated in Table 3 and Table 4. This finding is in agreement with a previous study that did not find positive associations between O_3 and Acute Lower Respiratory Infection (ALRI) admissions Ho Chi Minh City, Vietnam from 2003 to 2005 (Le *et al.*, 2012). Interestingly, hospital admissions showed significant negative regression weights of T with unstandardized β weights of –0.134 ($p < 0.005$) and –0.161 ($p < 0.002$) for Male-OPD and Female-OPD, respectively. This finding is in accordance with previous studies highlighting the outbreak of influenza virus and respiratory diseases during the cold period (Amin *et al.*, 2013; Green *et al.*, 2013; McAllister *et al.*, 2013).

Three-Dimensional Plots of Principal Component Analysis (PCA)

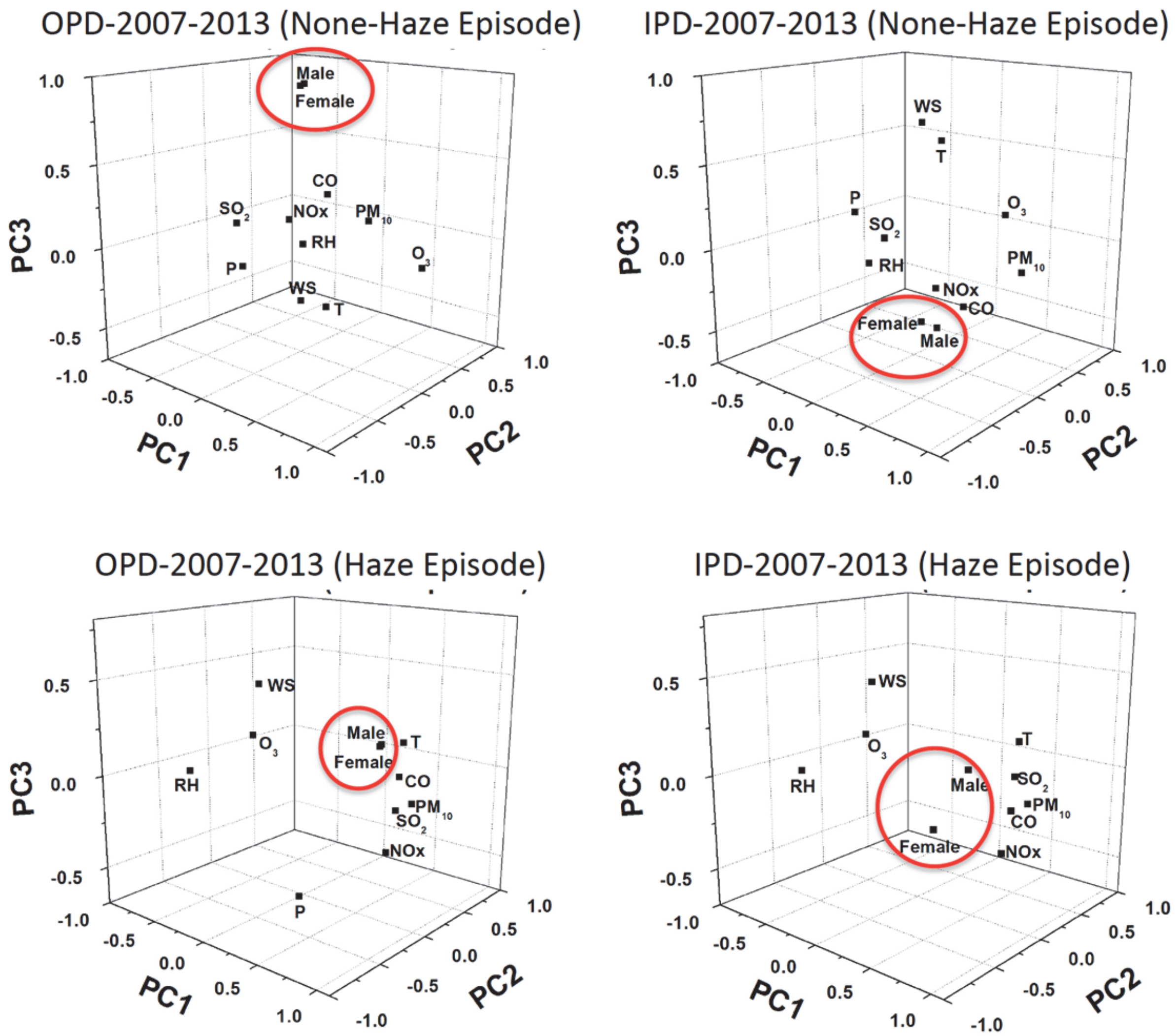
PCA as the multivariate analytical tool is generally used to decrease a set of original variables (i.e., trace gaseous concentrations, PM_{10}, meteorological parameters, and hospital admissions) and to extract a small number of hidden factors (principal components, PCs) for analyzing connections among the observed variables. Data submitted for the analysis were arranged in a matrix, where each column corresponds to one parameter and each row represents the number of samples. Data matrixes were assessed through PCA allowing the summarized data to be further analyzed and plotted in three dimensions (3D) by employing Varimax rotations. As illustrated in Fig. 4, some clearest features can be described as follows. Firstly, 3D plots of both genders show a strong intimacy irrespective of hospital admission types and sampling periods. Secondly, 3D plots of wind speed, relative humidity, and temperature are highly deviated from both male and female hospital admissions. Thirdly, 3D plots of CO are close to IPD and OPD of both genders during haze/none-haze episodes. This findings are again consistent with those of MLRA, indicating that higher CO concentrations could lead to an increasing numbers of hospital admissions regardless of observing periods. In addition, it seems logical to conclude that meteorological parameters play a minor role on hospital admission for both genders.

General Population Exposure of Outdoor Activities to PM_{10} and $PM_{2.5}$

The estimated ILPE levels for general population exposure of outdoor activities are summarized in Table 5. According to the 2014 Report of the Labor Force Survey conducted by National Statistical Office (NSO), there is some information related to outdoor workers operating adjacent to the air quality observatory site. NSO reports the comparatively high average percentage contribution of agricultural farmers (36.8%) followed by outdoor market sellers (18.1%), general public transportation workers (12.1%), cultural art product sellers (12.0%), mechanical engineers (8.4%), construction labors (4.6%), electrical engineering technicians (4.0%), and outdoor administrative officers (3.8%) from 2007 to 2013. Since TMCS and CHOS are situated in the rural area surrounded by rice paddy fields, it appears reasonable to assume the predicted *ILPE* values represent those of agricultural farmers. On the contrary, YOS and TOS are located at city center and thus it seems rationale to interpret the calculated *ILPE* values as incremental lifetime particulate matter exposure of outdoor market sellers, general public transportation workers, and cultural art products sellers, respectively.

Several limitations and assumptions should also be considered before applying the concept of *ILPE*. Since micro-particle corrugation, adhesion and surface morphology can greatly affect the inhalation aerosol efficiency, this model might not be beneficial enough for particle-phase contaminants, but vapor phase (Adi *et al.*, 2008). Furthermore, this study is based on the assumption that the 6-year PM data is adequate for evaluating life time exposure of general population. In spite of these research constraints, some characteristic features of incremental lifetime exposure of PM_{10} during haze/non-haze periods were observed. Firstly, the highest binary ratios of $ILPE_{\text{Haze}}/ILPE_{\text{Non-Haze}}$ of PM_{10} were observed in 2007 with the value of 2.52. Secondly, the $ILPE_{\text{Haze}}/ILPE_{\text{Non-Haze}}$ ratios larger than two were observed for four consecutive years from 2007 to 2010. The annual haze crisis during these four years has had a negative impact on the tourism, transport and economic sectors of nine northern provinces, which include Mae Hon Son, Uttaradit, Lumphoon, Lumphang, Phayao, Phrae, Nan, Chiang Rai, and Chiang-Mai. Agricultural waste burning, uncontrolled biomass burning as well as the atmospheric inversion in mountainous areas of Chiang-Mai during cold period appear to be responsible for this circumstance. Thirdly, the lowest $ILPE_{\text{Haze}}/ILPE_{\text{Non-Haze}}$ ratio was measured in 2011 with the value of 1.52. This can be explained by heavy rainfall for March over the area of northern Thailand in 2011, which was an extraordinary 344% above the annual average. Apart from high precipitation in the first quartile of 2011, the local authority of Chiang-Mai had raised several successful "stop-burning campaigns", which subsequently lead to the great reduction of PM levels.

Overall, this study has numerous limitations due to the nature of statistical models. The study was limited by the ecological fallacy; it was assumed that the increase in OPD and IPD patients was caused exclusively by a rise in respiratory disease occurrence. Actually, several factors


OPD-2007-2013 (None-Haze Episode)

IPD-2007-2013 (None-Haze Episode)

OPD-2007-2013 (Haze Episode)

IPD-2007-2013 (Haze Episode)

Fig. 4. Three-dimensional plots of PC1, PC2 and PC3 during the haze and non-haze periods from 2007 to 2013.

could have influenced the hospital admission records. For instance, human errors and biases in recording data and unstable hospital admission policies and clinical diagnoses on admissions were likely to have substantial effects on the credibility of hospital admission records. More importantly, NHCM does not cover all hospital services in Chiang-Mai province because the majority of the upper middle class prefers to use private hospital services due to shorter waiting times and freedom in selecting physicians. It is also crucial to emphasize that this study did not include other harmful trace gaseous species due to the limitations of the dataset provided by PCD and TMCS. Other confounding factors, such as smoking habits, genetic susceptibility to respiratory diseases and the distance from a home to potential air pollution sources, can also play important roles in governing both OPD and IPD patient numbers. The main benefits of this study can be characterized as the employment of weather and air pollution data spanning 7 years to investigate OPD and IPD patient numbers as functions of meteorological data and trace gaseous levels in Chiang-Mai city. This study highlights the vulnerability of children to respiratory diseases for both genders. MLRA revealed significantly higher impacts of CO on hospital admissions in comparison with other trace gaseous species. The anti-burning and smog prevention campaigns were highly successful in decreasing air pollution levels and thus in reducing hospital admissions during the haze episode.

CONCLUSION

In Chiang-Mai, hospitalizations as a consequence of respiratory diseases increased during the haze episode. Proactive infrastructure support for air quality monitoring as well as a network of anti-burning and smog prevention campaigns are required. Public health policies should be specifically designed to protect children from air pollution exposure, particularly CO, during haze episodes.

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Table 5. Incremental lifetime exposure of PM_{10} and $PM_{2.5}$ collected during the haze and none-haze periods at CMOS, YOS, TOS and CHOS from 2007 to 2013.

	Male			Female		
	PM_{10}-Haze [g]	PM_{10}-None-Haze [g]	$PM_{2.5}$-Haze [g]	PM_{10}-Haze [g]	PM_{10}-None-Haze [g]	$PM_{2.5}$-Haze [g]
CMOS-2007	3.338 ± 0.576	1.323 ± 0.776		1.838 ± 0.317	0.729 ± 0.427	
CMOS-2008	2.313 ± 0.568	1.053 ± 0.519		1.273 ± 0.313	0.580 ± 0.286	
CMOS-2009	2.584 ± 0.674	1.150 ± 0.600		1.422 ± 0.371	0.633 ± 0.330	
CMOS-2010	2.648 ± 0.391	1.145 ± 0.726		1.458 ± 0.215	0.630 ± 0.400	
CMOS-2011	1.514 ± 0.635	0.996 ± 0.522		0.834 ± 0.349	0.548 ± 0.287	
CMOS-2012	2.171 ± 1.114	1.090 ± 0.541		1.195 ± 0.613	0.600 ± 0.298	
YOS-2011			1.833 ± 0.503			1.009 ± 0.277
YOS-2012			1.711 ± 0.718			0.942 ± 0.395
TOS-2011			1.748 ± 0.466			0.963 ± 0.257
TOS-2012			1.683 ± 0.589			0.927 ± 0.324
CHOS-2011			1.717 ± 0.466			0.945 ± 0.257
CHOS-2012			1.651 ± 0.635			0.909 ± 0.350

Department of health 2005 (Average Body Weight)

Male: 58.25 ± 9.76 kg/Female: 54.95 ± 10.48 kg

Life Expectancy

Male: 69.9 years/Female: 74.9 years (Source: National Statistical Office Thailand, Survey of Population Change 1995–1996)

Inhalation Rate

Male: 0.89 m^3/h (USEPA 1994)

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