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Original Article

Health risk and predictive equation for $PM_{2.5}$ using TSP and PM_{10} variables in office buildings

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Abstract

Total suspended particle (TSP) and particulate matter (PM_{10} and $PM_{2.5}$) were measured at 35 office buildings in Thailand. This study aimed (1) to characterize the concentrations of TSP, PM_{10}, and $PM_{2.5}$ in office buildings, (2) to determine health risk indexes, and (3) to investigate the predictive equations for $PM_{2.5}$. Particle air sampling equipment and a self-administered questionnaire were used as the tools. Average concentrations of TSP, PM_{10}, and $PM_{2.5}$ were found at 52.0±15.5, 44.3±12.2, and 31.3±10.4 $\mu g/m^3$, respectively. Health risk assessments regarding exposure to PM_{10} and $PM_{2.5}$ were at moderate health hazard levels. A multiple linear regression model was used to create the predictive equation. The results verified that $PM_{2.5}$ concentration could be well estimated under known PM_{10} and TSP with the r^2 value of 0.88. These findings could help provide the possibility to estimate a non-monitoring value in terms of the available data.

Keywords: $PM_{2.5}$, PM_{10}, TSP, health risk assessment, multiple linear regression

1. Introduction

Presently, people spend up to 90% of their time indoors and many spend most of their working hours in an office environment leading to many kinds of illnesses (Lee & Koo, 2015). Indoor air pollution has been recently raised as a major concern to businesses, occupants and employees because it can impact their health, comfort, wellbeing and productivity (U.S. Environmental Protection Agency [US.EPA], 1997). Particle pollutions are abundant in all indoor environments and one of the major causes of death (Wang, Gong, Xu, & Zhang, 2017). Moreover, exposure to such particles can affect both the lungs and heart.

Numerous scientific studies have linked particle pollutions exposure to a variety of health problems range from simple respiratory symptoms to morbidity and mortality depending on duration of exposure and concentration of pollutants, including premature death among people with heart or lung disease, irregular heartbeat, aggravated asthma, decreased lung function and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty

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breathing (Chullasuk, Chapman, & Taneepanichskul, 2016; US.EPA, 2020). Particle pollutions can be classified into two groups, i.e., settled or total suspended particle (TSP) and respiratory or particulate matter (PM) (Barber, Dawson, Battams, & Nicol, 1991). Normally, the primary exposure pathways of humans to particle pollutions include inhalation, skin contact, and digestion (Melymuk, Demirtepe, & Jílková, 2020). Among these pathways, inhalation is a significant route of $PM_{2.5}$ and PM_{10} exposure (Yunesian, Rostami, Zarei, Fazlzadeh, & Janjani, 2019).

Several studies have ranked indoor particle as an important environmental health problem (Cincinelli & Martellini, 2017; Tham, 2016; US.EPA, 2019). Regarding economic aspects, the analyzing methods for fine particles are quite difficult and expensive. To overcome these challenges, researchers have endeavored to better understanding the differing viewpoints regarding their experience using various methods. Some have developed methods to investigate the relationship between various kinds of particle pollutions in terms of TSP and PM in size 10 and 2.5 micrometers (PM_{10}, and $PM_{2.5}$) in the monitoring networks (Iizuka *et al.*, 2014; Munir, 2017; Reggente *et al.*, 2015). However, those methods remain hard to understand. Notably, the study of Yang *et al.* (2018) proposed a common method to predict the trends and relationships among the materials of interest, i.e., linear regression analysis. In statistics, it refers to a linear approach to modeling the relationship between a scalar response (dependent variable) and one or more explanatory variables (independent variables). The case of one explanatory variable is called simple linear regression while multiple explanatory variables is called multivariate linear regression model (Freedman, 2009).

Based on the challenges mentioned above, a few studies have conducted analyses of regression models among indoor air pollutants. This study aimed to determine the levels of TSP, PM_{10}, and $PM_{2.5}$ in office buildings, so as to evaluate the health risk levels and their relationships using the linear regression model. The result could help organizations or inspectors provide possible ways to understand the current situation and estimate a non-monitoring value in terms of data available.

2. Materials and Methods

2.1 Collection instrumentation and procedure

Particle air sampling equipment was used as a tool in this study. The collection method involved using an air sampling method following the National Institute for Occupational Safety and Health guidelines (National Institute for Occupational Safety and Health [NIOSH], 1998). NIOSH collection method number 0500 (Issue 2) and 0600 (Issue 3) were applied to specify the sampling procedure for total (TSP) and respiratory (PM_{10} and $PM_{2.5}$) dust, respectively. Measurements were made during an 8-hour specified period (US.EPA, 1997). Sampling points were verified in a ratio of one per 500 m^2 following the guideline for less than 3,000 m^2 in total floor area. During field data collection, sampling points were sited at least 0.5 meter from corners, walls, and windows. To enable inclusion of all subjects, 35 individual office areas with mechanical ventilation were defined as subjects in this study. Subjects of TSP, PM_{10}, and $PM_{2.5}$ were calculated using the following Equation (1).

$$C = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 10^3 \qquad (1)$$

Where C is the concentration of PM (mg/m^3); W_2 and W_1 are the post-sampling weight of sample-containing filter and tare weight of filter before sampling (mg), respectively; B_2 and B_1 are mean post-sampling weight and mean tare weight of blank filters (mg), respectively; and V is an air volume sampling (L) at a flow rate of 1.7 L/min.

2.2 Questionnaire design

To determine the degree of risk, the details of personal and working behaviors were collected using a self-administered questionnaire. The study was conducted during hot season (March to May) in 2019 among office staffs working in an academic institution in Thailand. The inclusion criterion to select the population was working in an office with more than six months working experience. The 35 participants were enrolled and reported the information concerning demographics, life style behaviors, and their health status by questionnaire. This study was approved by the Ethics Committee for Research Involving Human Subjects (No. 2019-153) before collecting field data. Subjects provided written consent after being informed of the objectives of the study and procedures.

2.3 Health risk assessment

Human health risk assessment is the process to evaluate the probability of adverse health effects from contaminated environment exposure. It includes four basic steps as described below. First, hazard identification, PM_{10} and $PM_{2.5}$ hazards in office building were identified. Second, regarding dose-response assessment, the risk from inhalation of non-carcinogens was discussed. Reference concentrations (RfC) were sought from relevant studies. Then, exposure assessment, the exposure was assessed by determining how much PM_{10} and $PM_{2.5}$ affected human health, and chronic daily intake (CDI) was evaluated using Equation (2). Where C is the concentration of PM. IR is the average adult inhalation rate of 0.66 m^3/hr (16 m^3/day) (US.EPA, 2011). While ET, EF, ED, BW, AT, and their unit measurement are detailed as exposure time (hours/day), exposure frequency (days/year), exposure duration (years), body weight (kilograms), and average affecting time (365 days), respectively. Moreover, (4) Risk characterization, this comprised the hazard quotient (HQ) calculated following Equation (3). To estimate the senses of control, HQ<1 refers to the non-hazard level, 0.1 to 1.0 refers to low risk level, 1.1 to 10 refers to moderate hazard level, and HQ>10 refers to high risk level (Dennis Lemly, 1996).

$$CDI = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT} \qquad (2)$$

$$HQ = \frac{CDI}{RfC} \qquad (3)$$

2.4 Regression model

Statistical model were used in this study to determine the relationship among TSP, PM_{10}, and $PM_{2.5}$ in terms of their quantity. Multivariate linear regression (MLR) is based on the approximate linear relationship between an independent variable and a dependent variable which is fitted to predict the linear equation (Yang, Sun, & Guo, 2018). MLR can be formulated according to Equation (4).

$$y = b_0 + b_1 x_{1i} + b_2 x_{2i} + \ldots + b_k x_{ki} + \varepsilon \quad (4)$$

Where b_k is the regression coefficients, x_k is the explanatory variables, i is an constancy integer (1, 2, … k), and ε is stochastic error associated with the regression.

After the regression equation is established, the model's ability to predict is determined; the testing methods needed include standard deviation (SD.) and correlation coefficient (r) tests. Only when r is close to 1, can it describe the relationship between y and x using a linear regression model. The results were also further checked for first-order autocorrelation problem by Durbine-Watson statistic test. If a value of 2.0 means, there reveals no autocorrelation detected in the sample. Values in a range from zero to 2.0 indicate positive autocorrelation and values from 2.0 to 4.0 indicate negative autocorrelation. All statistical analyses were completed using the Statistical Product and Service Solution (SPSS, Version 18.0, SPSS Ltd., USA).

3. Results and Discussion

3.1 TSP, PM_{10}, and $PM_{2.5}$ concentrations

Characteristics of the working environment were examined in all offices including temperature and ventilation in term of air exchange rate. Temperature was found in a range of 23 to 28 °C and averaged of 24.9±1.2 °C. Air exchange rate was in a standard level for general office of 2.0 m^3/m^2-hr. Data collected of TSP and PM (10 and 2.5 micrometers in size) are displayed in Figure 1. TSP concentration constituted the main pollutant in offices averaging of 52.0±15.5 µg/m^3 while those of PM were 44.3±12.2 and 31.3±10.4 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. As presented in Table 1, with the similar study site, the office concentrations of indoor PM in this study were at worldwide average levels (Nezis, Biskos, Eleftheriadis, & Kalantzi, 2019) which is higher than those reported in US and Belgium offices (Horemans & Van Grieken, 2010; Reynolds *et al.*, 2001), but much lower than those in China and Greek offices (Gemenetzis, Moussas, Arditsoglou, & Samara, 2006; Niu, Guinot, Cao, Xu, & Sun, 2015). Compared with the European Union (EU) air quality directive (50 and 25 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively) and US annual health standard (12 µg/m^3 for $PM_{2.5}$) (European Environment Agency, 2019; US.EPA, 2020), the PM levels in this study were slightly higher. Moreover, results were found of higher concentrations of indoor PM and TSP was generally found near open window areas, close to the main road with heavy traffic, and has the printer and photocopy machine inside. Hence, indoor air quality regulation is still required, and further work is needed to obtain to get more information to support more definitive occupant exposure.

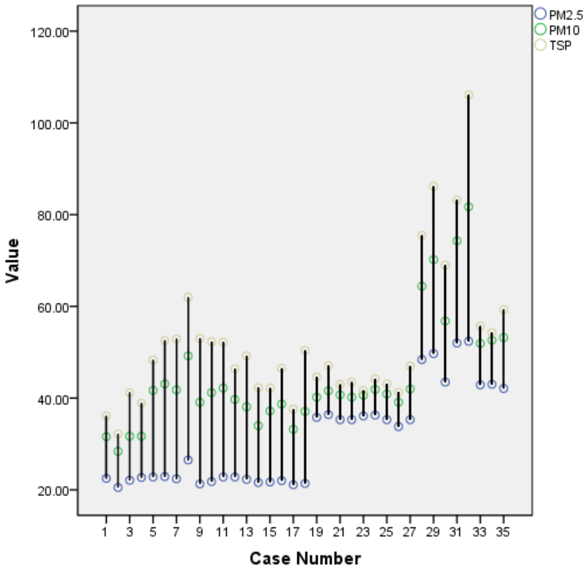


Figure 1. TSP and PM concentrations in µg/m^3

Table 1. PM concentrations in indoor air of office building

Place of Study	PM concentration (µg/m^3)	
	PM_{10}	$PM_{2.5}$
Worldwide	14.0 to 333.0	4.0 to 227.4
U.S. office	14.0 to 36.0	-
China office	333.0	213.0
Greek offices	118.0±68.0	91.0±56.0
Belgium offices	20.0±1.0	15.0±0.9
This study	44.3±12.2	31.3±10.4

3.2 Hazard quotient assessment

The results of personal and working behaviors among 35 participants working in offices were collected to further determine of degree of risk. The ages of subjects enrolled were between 41 to 45 years (52.5%) for females whereas for males were 31 to 40 years (68.8%). They reported average working hours and experience of 8.0±0.6 hours daily and 13.4±4.6 years, respectively. Details of individual body weight and working days yearly were also obtained and averaged 63.3±14.7 kilograms and 271.1±17.1 days, respectively.

Applying four steps of health risk assessment, the RfC of PM_{10} and $PM_{2.5}$ (0.011 and 0.005 mg/kg/capita, respectively (DoH, 2011)) were used to estimate health risk. Data used in this calculation are tabulated in Table 2. The averaged results of CDI for PM_{10} and $PM_{2.5}$ were 0.052±0.035 and 0.038±0.027 mg/kg/day, respectively. The mean hazard quotient (HQ) for PM_{10} (4.7±3.2) and $PM_{2.5}$ (7.5±5.4) among all participants was >1, indicating an unacceptable risk for human health. These values are in the moderate hazard level (1.1≤HQ≤10). Moreover, the results were found few cases with HQ higher than 10 due to a highly level of particle concentrations in occupant's rooms. Notably, the present results indicated a significant risk from inhalation exposure of

Table 2. Variables for health risk determination

Variable	Range of value (Min – Max)	Unit
Concentration of $PM_{2.5}$	20.5 – 52.4	μg/m^3
Concentration of PM_{10}	28.4 – 81.7	μg/m^3
ET	6.0 – 10. 0	Hours
EF	265.0 – 318.0	Days/year
ED	3.0 – 20.0	Years
BW	39.0 – 110.0	Kilograms

these indoor air pollutants. Improving office procedures should be recommended, for example, controlling of PM sources, upgrading ventilation, and using air cleaners (US.EPA, 2017).

3.3 Predicting of $PM_{2.5}$

MLR modeling of indoor $PM_{2.5}$ concentration was conducted to create the predictive equation using other pollutant variables including TSP and PM_{10}. A total of 35 sampling points for $PM_{2.5}$, PM_{10}, and TSP in office buildings were collected. The model input variables were selected from the primary data and presented in Table 3. Notably, other variables including relative humidity, temperature, wind speed, and speed of air exchange were not included in this study.

By considering regression assumptions, the value of correlation coefficient (r) between the collected data could be used as a degree indicator to determine where $PM_{2.5}$ measured indoor was attributed to. It provided the proportion of the variation in the dependent variable ($PM_{2.5}$ concentration) as explained by the independent variables (the levels of TSP and PM_{10}). Results of MLR analysis to predict $PM_{2.5}$ are summarized in Table 4.

According to Table 4, the best fitted equation provided the r^2 value of 0.882. Thus, approximately 88.2% of variation in the $PM_{2.5}$ concentration could be explained by independent variables of PM_{10} and TSP. The coefficients of the all regressions were highly significant (P value <0.01). Moreover, the linear graphs of the contribution of TSP and PM_{10} to $PM_{2.5}$ concentrations were plotted in Figure 2(a) and (b), respectively. The output revealed an unsatisfied distribution of values corresponding to the reported Durbin-Watson's values of 0.439 and 0.410. When the value of Durbin-Watson test statistics is close to 2, it indicates that the assumption is satisfied (Elbayoumi, Ramli, & Yusof, 2015).

4. Conclusions

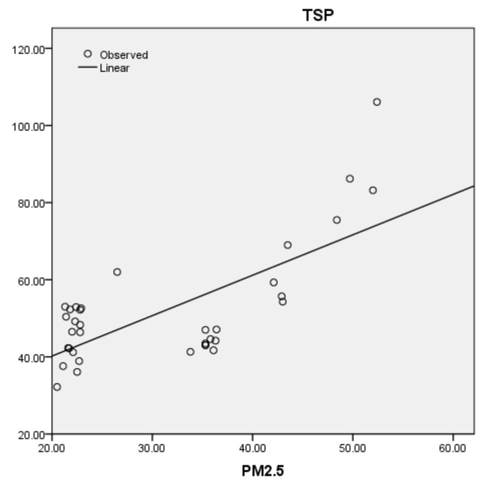
Average values of TSP, PM_{10}, and $PM_{2.5}$ were 52.0±15.5, 44.3±12.2, and 31.3±10.4 μg/m^3, respectively. Compared with IQA standard requirement, the reported values were slightly high. From this finding, higher level of indoor PM and TSP were generally found near open window areas and close to the main road with the heavy traffic. To further determine of health risk in terms of HQ, a cross-sectional study was conducted using a self-administered questionnaire to collect information of life style behaviors and health status. Results indicate that both HQ for PM_{10} and $PM_{2.5}$ were at moderate health hazard level (4.7±3.2 for HQ-PM_{10} and

Table 3. Dependent and independent variables used in MLR model.

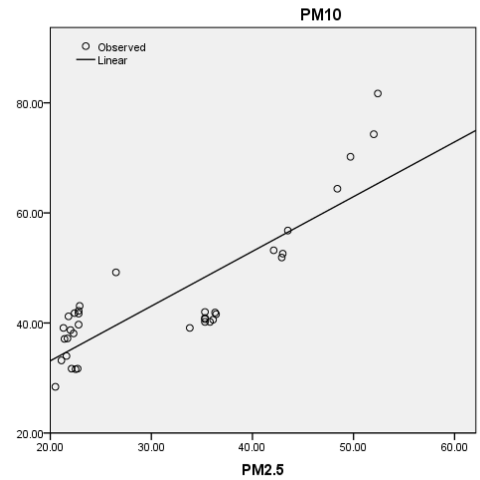
Variables	Type of variables	Response names	Abbreviation	unit
Y_1	Dependent	$PM_{2.5}$ concentration	$PM_{2.5}$	mg/m^3
X_1	Independent	PM_{10} concentration	PM_{10}	mg/m^3
X_2	Independent	TSP concentration	TSP	mg/m^3

Table 4. Predictive results of indoor $PM_{2.5}$ using MLR analysis

Pollutant	Equation	r^2	Durbin-Watson
$PM_{2.5}$	$PM_{2.5} = 0.477\ (TSP) + 6.468$	0.500	0.410
$PM_{2.5}$	$PM_{2.5} = 0.722\ (PM_{10}) – 0.743$	0.718	0.439
$PM_{2.5}$	$PM_{2.5} = 1.956\ (PM_{10}) – 1.014\ (TSP) – 2.691$	0.882	1.273



(a)



(b)

Figure 2. Contribution of TSP and PM_{10} to $PM_{2.5}$ concentration; (a) TSP and $PM_{2.5}$ (b) PM_{10} and $PM_{2.5}$

7.5±5.4 for HQ-$PM_{2.5}$). Notably, the indoor air improvement strategies are required. Further analysis was conducted to determine the predictive equations for $PM_{2.5}$ from other relevant variables. The outcomes provided the proportion of variations in $PM_{2.5}$ concentration as explained by both levels of TSP and PM_{10} with the r^2 value of 0.88 and Durbin-Watson's value of 1.273.

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