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Assessment of the Association between $PM_{2.5}$ Exposure and Children's Health Risks in Ho Chi Minh City, Viet Nam

Tinh Huu Ho[1, 2], Diep Ngoc Le[1], Chinh Van Dang[1], Thao Thi Bich Pham[3], To Thi Hien[4,5], and Supat Wangwongwatana[2*]

[1]The Institute of Public Health, Ministry of Health, 159 Hung Phu Street, Ward 8, District 8, Ho Chi Minh City 700000, Viet Nam
[2]Faculty of Public Health, Thammasat University (Rangsit Campus), Khlong Luang, Pathum Thani, 12121, Thailand
[3]Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand
[4]Faculty of Environment, University of Science, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Vietnam.
[5]Vietnam National University, Ho Chi Minh City, Vietnam

*Corresponding author: supat.w@fph.tu.ac.th
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Abstract

Air pollutants can exacerbate respiratory diseases among children. This study investigated the short-term effects of the ambient fine particulate matter ($PM_{2.5}$) in hospital admissions due to acute lower respiratory infection (ALRI) among children under five years old in Ho Chi Minh City (HCMC). The study collected 50,778 children hospital recorded hospitalized by ALRI in all pediatric hospitals during 2016 – 2019. Daily $PM_{2.5}$ datasets were obtained from the US Consulate and the Vietnam National University. The generalized linear model with the family of Quasi-Poisson was applied to assess the associations. The models controlled seasonal and long-term trends and potential confounding factors. On average, over the period 2016-2019, the daily $PM_{2.5}$ concentration in HCMC was 28.2 $\mu g/m^3$ (± 11.4) and children below 5 years were hospitalized for ALRI was 35 (± 12) children. Each 10 $\mu g/m^3$ increase in daily $PM_{2.5}$ concentration had a significant excess risk (ER) was 1.86% (95% confident interval: 0.24% ~ 3.52%) of ALRI admission after six days of exposure. Exposure to $PM_{2.5}$ resulted in more hospital admissions in male children (ER = 2.43%, 95% CI: 0.40% ~ 4.49%) and children aged 2 to under five years old (ER = 3.15%, 95% CI: 0.25% ~ 6.14%). The annual $PM_{2.5}$ concentration in HCMC exceeded the Air Quality Guideline of the World Health Organization and significantly increased ALRI hospital admissions among children. Therefore, mitigation measures to reduce $PM_{2.5}$ emissions should be implemented.

Keywords: Air pollution; Fine particulate matter; Lower respiratory infection; Acute lower respiratory infection.

1. Introduction

Air pollution has become a popular risk factor that can cause a wide range of diseases. Compared to the ranking in the year 2017, air pollution took the position of high fasting plasma glucose to become the 4th risk factor of the total number of deaths from all causes in 2019 (IHME, 2019b, 2020b). Nearly 6.75 million early deaths and 213 million years of healthy life lost (YLLs) were accounted for air pollution in

2019 worldwide (IHME, 2020b). Among pollutants, ambient $PM_{2.5}$ (particulate matter with aerodynamic diameters not larger than 2.5 μm) led to the hugest burden of disease worldwide, making up for 4.14 million deaths (118 million YLLs), a considerable increase compared to 3.5 million in 1990 (Cohen *et al.,* 2017; IHME, 2020b). Ambient $PM_{2.5}$ was also ranked the 6th among 69 risk factors in the global burden analysis (IHME, 2020b), and around 91% of the world's population (93% of its children) was exposed to $PM_{2.5}$ at levels that exceed the World Health Organization (WHO) recommended annual mean (10 μg/m^3) in 2019 (WHO, 2018b).

Exposure to $PM_{2.5}$ can result in a myriad of adverse health effects, including acute and chronic diseases, non-communicable and infectious diseases (Cohen *et al.,* 2017; Kim *et al.,* 2015). Together with the elderly group, children are the most vulnerable group to air pollution. Children own characteristics that can facilitate adverse effects of air pollution, such as immature immune systems, higher breathing rates, and narrowed airways (DeFlorio-Barker *et al.,* 2019; Ostro *et al.,* 2009). Children usually spend physical activities outside in potentially polluted air and near the ground where some pollutants reach peak concentrations (WHO, 2018a).

Respiratory diseases have been popular among children, especially children under five years. In 2019, lower respiratory infection (LRI) was the 2nd leading cause of death in low-income countries, the top 6 in high-income countries, and the 4th in the top 10 global causes of disability-adjusted life years (WHO, 2019). It was estimated around 170 thousand deaths among children under five years old worldwide in 2019 were caused by lower respiratory infection, accounting for 13% of total deaths in this age group (IHME, 2020a).

Air pollution has emerged as a hot issue in Vietnam, especially in megacities such as Ho Chi Minh City (HCMC). The HCMC's annual mean ambient $PM_{2.5}$ was 42 μg/m^3 in 2016 (WHO 2021a) and 29.6 μg/m^3 in 2017 (GreenID, 2018). These results far surpassed the Air 2005 Quality Guideline of the WHO of 10 μg/m^3 (WHO, 2006), recently updated in 2021 to 5 μg/m^3 (WHO, 2021), and the National Technical Regulation on Ambient Air Quality (NAAQ)" (QCVN 05:2013/BTNMT) of 25 μg/m^3 (MONRE, 2013). In 2017, up to 222 days in HCMC exceeded the WHO air quality guidelines for $PM_{2.5}$ (GreenID, 2017). Respiratory infection was also a common disease among Vietnamese children. Although the number of deaths of all ages for LRI slightly reduced by 1.2% during 2009 – 2017, it was still ranked 9th cause of the total number of deaths in 2019 in Vietnam (IHME, 2019a). Among children under five years old, the annual number of deaths due to this cause was around 14% of total causes in 2019 (WHO, 2017).

Short-term exposure to $PM_{2.5}$ has been reported to increase the risk of hospital admission due to LRI among children (K. N. Kim *et al.,* 2020; Linares and Díaz, 2010; Luong *et al.,* 2017; Luong *et al.,* 2020; Nhung *et al.,* 2017; Nhung *et al.,* 2018; Ostro *et al.,* 2009; Pu *et al.,* 2021). In Viet Nam, each 10 μg/m^3 increase in $PM_{2.5}$ was reported to increase 2.2% in the risk of daily hospital admission of all respiratory diseases among children under five years on the same day of exposure (Luong *et al.,* 2017), 3.51% risk of acute lower respiratory infection (ALRI) admission after three days of exposure (lag3) (Luong *et al.,* 2020). An interquartile range $PM_{2.5}$ increase (39.4 μg/m^3) associated with a 6.3% risk of hospital admission due to pneumonia in children 1 – 5 years old (Nhung *et al.,* 2018).

Studies on the health impact of $PM_{2.5}$ and respiratory diseases among children are still relatively sparse in Viet Nam, especially in HCMC. The newest one in HCMC focused on $PM_{2.5}$ and ALRI among children in only one hospital (Luong *et al.,* 2020), which may not provide a full picture of HCMC. Meanwhile, another one conducted before 2010 may be obsoleted and only focused on PM_{10}, NO_2, SO_2, and O_3 (Mehta *et al.,* 2011). Therefore, this study aimed to identify the association between $PM_{2.5}$ concentration and daily ALRI hospital admission among children under five years old from 2016 to 2019 in HCMC.

2. Methodology

2.1 Study design and research site

A time-series study was carried out in HCMC in the south of Vietnam (Figure 1). HCMC is the most populous city and the center of Viet Nam's economy, culture, and education. The city area is around 2095 km², comprising 19 urban and five suburban districts, and the population is approximately 9 million people (51.3% female, 6.1% under five years old, 79.2% urban) (GSO Vietnam, 2020). The city's climate has two clear seasons: the rainy season (May to November) and the dry season (December to April the following year).

2.2 Health data collection

Data on daily ALRI hospital admissions were collected at all three pediatric hospitals in HCMC. Children's Hospital No.1 and Children's Hospital No.2 are located in the center, whereas Children Hospital City is on the outskirt of the city. Children Hospital No.1 was built in 1954 and had 1400 beds, with more than 1600 employees. The average number of outpatients and inpatients was 4600 and 300 children per day, respectively. The Children's Hospital No.2 was established in 1978 with 1400 beds, 5000 employees currently, and around 5000 outpatients, and 300 inpatients per day, respectively. The newest one – Children Hospital City, was built in 2017 with 1092 beds, 1100 employees, about 1400 outpatients, and 60 inpatients per day.

The study focused on ALRI among children under five years old in HCMC. ALRI was defined as the hospital diagnosis based on the International Classification of Diseases, 10th revision code (ICD-10) from J12 – J18 or J21 (Horne *et al.,* 2018; Luong *et al.,* 2020; Mehta *et al.,* 2013; Zhang *et al.,* 2019). The diseases were divided into subgroups, such as pneumonia (J12 – J18) and bronchitis or bronchiolitis (J21) (Darrow *et al.,* 2014; Nhung *et al.,* 2019). Information of gender, age, hospitalization date, discharge date, and ICD-10 of the discharge diagnosis were extracted from the computerized hospital records.

The inclusion criteria were inpatient children under five years old with an address in HCMC, the discharged diagnosis of ALRI based on ICD-10 code from J12 – J18 and J21. Neonatal admissions (< 28 days) were excluded since these are likely to be influenced by perinatal conditions, and all repeated visits occurring within two weeks were only selected in the first visit record to avoid double counting (Mehta *et al.,* 2011). This study used secondary data, and personal information used only for checking the repeated hospital admission and was not disclosed.

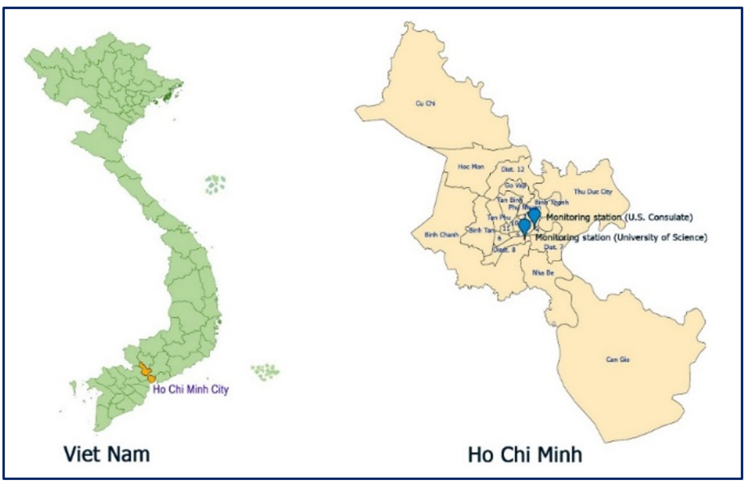

Figure 1. Geographical position of Ho Chi Minh City and the location of the $PM_{2.5}$ monitoring stations

Thus, the consent form was not applied. The ethical clearance of this study was approved by The Human Research Ethics Committee of Thammasat University, Thailand, and the Human Research Ethics Committee of the Institute of Public Health in HCMC, Viet Nam.

2.3 $PM_{2.5}$ and meteorological data collection

Data on $PM_{2.5}$ from 2016 to 2019 were collected from two sources, including the $PM_{2.5}$ monitoring station of the Ho Chi Minh City US Consulate (10.7835°N, 106.7006°E, hourly value) (AirNow, 2020) and the University of Science - Vietnam National University HCMC (VNUHCM-US) - (10.7626°N, 106.6819°E, daily value) (Figure 1). Details of the collecting data process and cleaning dataset are described elsewhere (Ho *et al.,* 2023). The city's daily level concentration of $PM_{2.5}$ was calculated by averaging the 24-h hourly data from the two monitoring stations. Overall, 1438/1461 days from 2016 to 2019 had $PM_{2.5}$ data (1.6% missing).

Data on temperature and relative humidity were collected from the National Centers for Environmental Information (https://www.ncei.noaa.gov) and the National Center for Hydro-Meteorological Forecasting in HCMC. The final dataset of temperature and relative humidity was the geometric mean of the values from the two sources.

2.4 Data analysis

The health outcome database was described using frequency, mean (standard deviation), and median (interquartile range). The daily concentration of $PM_{2.5}$ and weather parameters were presented with mean and standard deviation (or median and interquartile range). Line – and – bar plots were also used to illustrate daily $PM_{2.5}$ levels and numbers of health outcomes.

The generalized linear models with the family of quasi-Poisson distribution were applied to assess the association between daily concentration $PM_{2.5}$ and ALRI. Potential confounding factors, including temperature, relative humidity, day of the week, and national holidays, were controlled by integrating them into the model. This study estimated the lagged effects of $PM_{2.5}$ up to 7 days (Croft *et al.,* 2019; I.-S. Kim *et al.,* 2020; Luong *et al.,* 2020; Nenna *et al.,* 2017) applying the distributed lag linear models (DLM) (Gasparrini, 2011). In the DLM, the different lag effects were adjusted for each other by adding all lag effects into the model. The DLM overcame the possible limitations of the single-day lag models, which estimated the lag effect separately (Zheng *et al.,* 2017).

In the DLMs models, three cross-basis matrices for the three predictors ($PM_{2.5}$, temperature, and relative humidity) were built and then put in the model formula of a regression function. The effect of $PM_{2.5}$ exposure was assumed to be linear with the health outcomes, and the lag structures were set up to 7 days with an integer function. The cross-basis matrices of temperature and relative humidity were fitted in the model with B-spline function and strata for lags (0-1, 1-3, 3-5, and 5-7 days). The study controlled seasonal and long-term trends using a natural spline with seven degrees of freedom (df) per year (Bhaskaran *et al.,* 2013). The plot of residuals over time and the Dickey-Fuller test were used to examine the stationary of the model after control. The day of the week was put in the models as a categorical variable, and a dummy variable was used for a national holiday in years. The population in HCMC from 2016 to 2019 was assumed to be stable. The general analytical model was as follows:

$$Y_{s,t} \sim quasi - Poisson\ (\mu_t)$$

$$Ln(\mu_{s,t}) = \alpha + spl(time, df = 28) + \gamma_1 PM_{s,t} + \gamma_2 Temp_{s,t} + \gamma_3 RH_{s,t} + \gamma_4 Dow + \gamma_5 Hol$$

Where; $Y_{s,t}$ was the observed daily count of hospital admissions in spatial unit s and period time t; α was the intercept; *spl* was the flexible spline function of time, using a natural cubic spline; *df* was the degree of freedom. $PM_{s,t}$ was the cross-basis matrix of $PM_{2.5}$ levels at each lag day in DLMs. $Temp_{s,t}$ and $RH_{s,t}$ were the cross-basis matrix of daily mean temperature and relative humidity in

DLMs, respectively. *Dow* was the categorical day of the week; *Hol* was the binary variable for a national holiday (1 for a holiday and 0 for a non-holiday).

The reliability of the model was checked with sensitivity analysis. The controlling long-term trends and seasonal patterns were tested with different degrees of freedom, six df per year and eight df per year. Time-stratified models with a stratum for each month nested in a year were also applied instead of the cubic B-spline to control long-term trends and seasonal patterns.

The results were presented as relative risk (RR), excess risk (ER = (RR – 1) x 100), and its 95% confidence interval (CI) for daily hospitalization for ALRI per 10 μg/m³ increase in $PM_{2.5}$. All statistical analyses were performed using R software version 3.5.3 (http://www.r-project.org), applying the packages including lubridate, tsModel, ggplot2, ggfortify, ggthemes, gridExtra, Epi, dlnm, and splines.

3. Results and Discussion

3.1 The distribution of daily ALRI hospital admissions among children under five years and $PM_{2.5}$ concentration, meteorological parameters in Ho Chi Minh City from 2016 – 2019

The general characteristics of the study variables were presented in Table 1 and Table 2, whereas Figure 2 illustrated the daily patterns of ALRI hospital admissions among children under five years old, $PM_{2.5}$ concentration, the average temperature, and the average relative humidity from 2016 to 2019 in Ho Chi Minh City. A total of 50,778 ALRI cases were admitted in three children's hospitals in HCMC during 2016 – 2019. The daily average of ALRI cases was 35 patients, and the number of males was around 1.5 times higher than that of females. More than two-thirds of ALRI cases were one or below one year old, and the average daily case was 24 cases among this group compared to 11 cases from 2 to the under five years old. The total number of cases of pneumonia was higher than bronchitis, resulting in 24 patients compared to 12 patients with bronchitis on average per day (Table 1).

The average daily $PM_{2.5}$ concentration in HCMC from 2016-2019 was 28.0 μg/m³. The average daily temperature and relative humidity were 28.6 Celsius and 74.5%, respectively. Out of the total of 1438 days from 2016-2019 had $PM_{2.5}$ data (23 days of missing data), 1,342 days (93.3%) had the daily average $PM_{2.5}$ concentration exceeded the WHO guideline values of 2021 (15 μg/m³). For the National Vietnamese daily average standard of 50 μg/m³, 66 days (4.6%) had the daily average $PM_{2.5}$ concentration exceeded the standard (Table 2).

The temporal pattern of ALRI hospital admissions had a seasonal fluctuation over a year. The daily number was low in the first quarter months, then gradually increased, peaked in the early months of the third quarter, and steadily decreased in the after months. The daily $PM_{2.5}$ concentration also showed fluctuation. The high concentration was from the last months of the year to the early months of the following year, then gradually declined to the lowest level at the middle of the year before going up again. Additionally, there was a clear seasonal signal in temperature and relative humidity. The daily average temperature started increasing from the beginning of the year, peaked in the middle of the year, and then decreased. Daily average relative humidity contrasted with temperature (Figure 2).

3.2 Estimating the association between $PM_{2.5}$ concentration and ALRI hospital admissions among children under five years in Ho Chi Minh City from 2016 to 2019

The long-term trends and seasonal patterns were controlled using a cubic B-spline with 28-degree freedom (Figure 3). The residual of ALRI data after being handled with the cubic B-spline showed stationary with a mean value of around 0 (Figure 4). The Dickey-Fuller test reported -10.919 and p-value < 0.01; thus, the model was stationary.

Table 1. Statistics of ALRI hospital admissions in children below 5 years in HCMC during 2016 – 2019

	Frequency distribution			Mean (SD)	Min – Max
	25th	50th	75th		
Total ALRI hospital admissions *(n=50,778)*	26	33	42	34.7 ± 12.1	2 – 77
Gender groups					
Male *(n=30,432)*	15	20	26	20.8 ± 7.8	1 – 53
Female *(n=20,346)*	10	13	17	13.9 ± 5.7	1 – 45
Age groups					
≤ 1 *(n=35,004)*	16	22	31	23.9 ± 10.8	2 – 67
2 – < 5 *(n=15,774)*	8	10	13	10.8 ± 4.3	0 – 27
ICD-10 code groups					
Pneumonia (J12 – J18) *(n=33,900)*	17	23	28	23.2 ± 8.1	2 – 55
Bronchitis (J21) *(n=16,878)*	7	11	15	11.6 ± 5.6	0 – 37

Table 2. $PM_{2.5}$ concentration, Temperature and Relative humidity in HCMC during 2016 – 2019

	Frequency distribution			Mean (SD)	Min – Max
	25th	50th	75th		
Temperature (^{0}C) *(n=1461)*	27.7	28.6	29.3	28.6 ± 1.3	22.6 – 32.5
Relative humidity (%) *(n=1461)*	68.5	75.4	81.5	74.5 ± 9.2	51.5 – 93.3
$PM_{2.5}$ (µg/m^3) *(n=1438 days, 23 missing days)*	19.8	25.6	35.3	28.0 ± 11.4	8.6 – 76.9
Number of days on which the daily average $PM_{2.5}$ concentration exceeded the WHO guidelines (n, %)*	1,342 (93.3%)				
Number of days on which the daily average $PM_{2.5}$ concentration exceeded the Vietnamese national standard (n, %)**	66 (4.6%)				

**: WHO air quality guidelines of 2021 (24-hour average), $PM_{2.5}$ concentration ≤ 15 µg/m^3*
***: The Vietnamese national standard (24-hour average), $PM_{2.5}$ concentration ≤ 50 µg/m^3*

The effect of each 10 µg/m³ increase in $PM_{2.5}$ to ALRI hospital admission when all lag terms modeled together using the DLMs were presented in Table 3. A significant effect of each 10 µg/m³ $PM_{2.5}$ increment to the number of ALRI admission was found at lag6 with the excess risk – ER of 1.86% (95% CI: 0.24% ~ 3.52%). In subgroup analysis, the significant associations were found in the male gender at lag6 (ER = 2.43, 95% CI: 0.40 ~ 4.49), the age group from 2 to under five at lag6 (ER = 3.15, 95% CI: 0.25 ~ 6.14).

All sensitivity analyses showed consistent results of the significant association between each 10 µg/m³ increase in $PM_{2.5}$ with a total of ALRI, ALRI in the male gender, and the age group from 2 to under five years old. Specifically, when using six df per year instead of seven df per year for controlling the time trend in the cubic B-spline, the excess risk of total ALRI, ALRI in the male gender, and ALRI in the age group 2 to under five at lag6 were 1.87% (95% CI: 0.20% ~ 3.57%); 2.49% (95% CI: 0.43% ~ 4.59%); 3.05% (95% CI: 0.10% ~ 6.09%). These excess risk numbers were 1.85% (95% CI: 0.24% ~ 3.49%); 2.42% (95% CI: 0.40% ~ 4.48%), and 3.19% (95% CI: 0.30% ~ 6.17%) when applying eight df per year in the cubic B-spline. Applying the time–stratified model for seasonality control

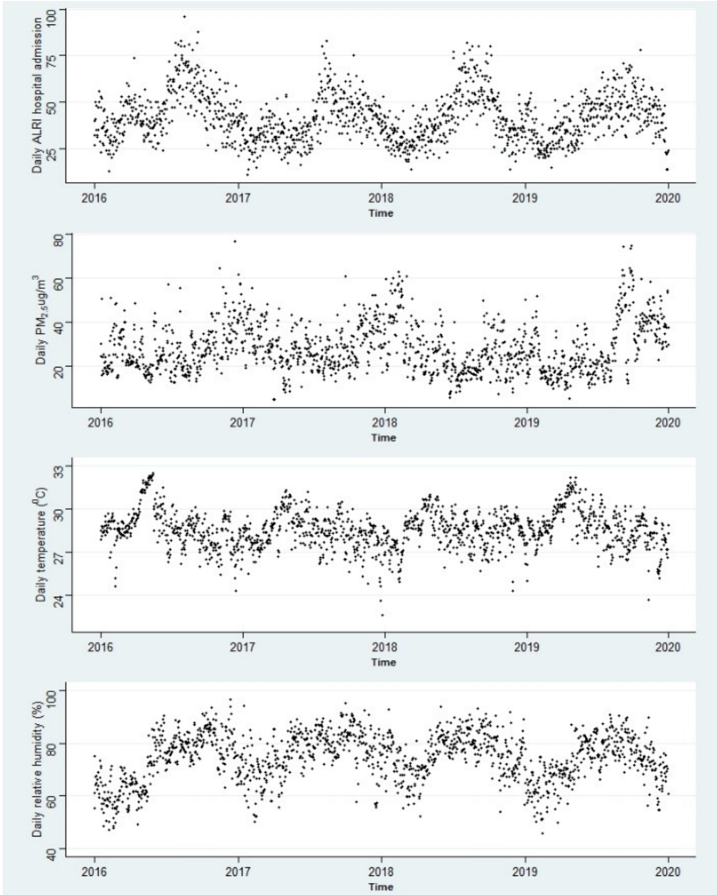

Figure 2. The daily number of ALRI hospital admissions among children under five years, $PM_{2.5}$ concentration, temperature, and relative humidity in Ho Chi Minh City from 2016 to 2019

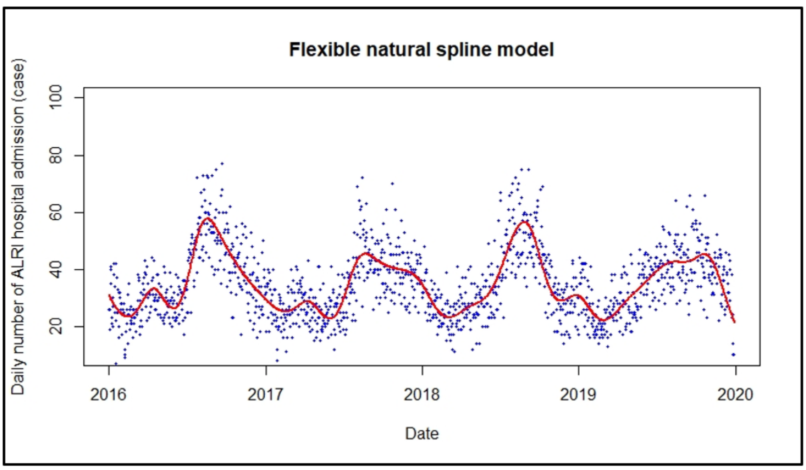

Figure 3. Using a natural spline model with 7 degrees of freedom per year for controlling seasonality and cycle among ALRI cases in Ho Chi Minh City from 2016 to 2019

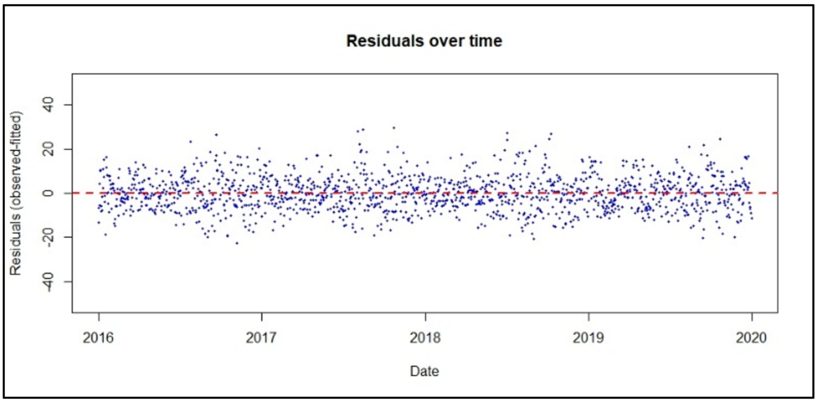

Figure 4. Residual of natural spline model with 7df per year applied for controlling seasonality and cycle among ALRI cases in Ho Chi Minh City from 2016 – 2019

Table 3. Results of the distributed lag linear models for estimating excess risk (ER) between each 10 µg/m³ $PM_{2.5}$ increasing and ALRI hospital admission among children under five years from 2016 – 2019 in Ho Chi Minh City

Lag (day)	Excess risk (95% confidence interval)						
	Total	Male	Female	Age ≤ 1	Age 2-<5	Bronchitis	Pneumonia
0	-0.33	-1.17	0.95	-0.66	0.46	-0.24	-0.37
	(-1.76~1.13)	(-2.94~0.62)	(-1.22~3.17)	(-2.34~1.05)	(-2.12~3.11)	(-2.56~2.14)	(-2.08~1.37)
1	-0.32	0.10	-0.94	-0.34	-0.27	-1.82	0.44
	(-1.95~1.34)	(-1.93~2.17)	(-3.37~1.55)	(-2.25~1.61)	(-3.20~2.74)	(-4.42~0.86)	(-1.52~2.44)
2	0.40	0.78	-0.16	0.15	0.91	-0.27	0.71
	(-1.24~2.08)	(-1.26~2.87)	(-2.61~2.35)	(-1.77~2.11)	(-2.04~3.96)	(-2.91~2.44)	(-(1.25~2.72)
3	0.60	0.95	0.07	0.93	-0.17	0.90	0.47
	(-1.05~2.26)	(-1.09~3.03)	(-2.37~2.56)	(-1.00~2.90)	(-3.08~2.82)	(-1.76 3.62)	(-1.48~2.47)
4	0.53	0.26	0.93	0.70	0.17	1.67	-0.04
	(-1.11~2.18)	(-1.76~2.32)	(-1.51~3.43)	(-1.22~2.65)	(-2.73~3.16)	(-0.97~4.39)	(-1.98~1.94)
5	-1.39	-1.98	-0.51	-1.20	-1.81	-1.25	-1.46
	(-2.98~0.23)	(-3.94~0.02)	(-2.89~1.94)	(-3.07~0.71)	(-4.61~1.07)	(-3.80~1.38)	(-3.35~0.48)
6	**1.86**	**2.43**	1.03	1.33	**3.15**	1.99	1.80
	(0.24~3.52)	**(0.40~4.49)**	(-1.39~3.50)	(-0.58~3.28)	**(0.25~6.14)**	(-0.63~4.68)	(-0.14~3.78)
7	-0.20	0.01	-0.53	-0.24	-0.23	0.14	-0.36
	(-1.61~1.23)	(-1.74~1.79)	(-2.63~1.62)	(-1.91~1.45)	(-2.72~2.32)	(-2.14~2.48)	(-2.04~1.35)

instead of the cubic B-spline model, each 10 µg/m³ increase in $PM_{2.5}$ was significantly associated with the excess risk at lag6 of total ALRI, ALRI in the male gender and ALRI in the age group from 2 to under 5 were 1.89% (95% CI: 0.22% ~ 3.59%); 2.48% (95% CI: 0.43% ~ 4.57%); and 3.45% (95% CI: 0.58% ~ 6.40%).

Overall, the study found a positive association between the daily $PM_{2.5}$ level and the number of ALRI hospital admissions. Each 10 µg/m³ increase in daily $PM_{2.5}$ concentration had an excess risk 1.86% (95% CI: 0.24% ~ 3.52%) of ALRI admission after six days of exposure (lag6). The findings strengthened scientific evidence of adverse health impacts of particulate matter among children due to lower respiratory infections. Its effect was different in magnitude and individual lagged effect in various studies. In a time-stratified case-crossover study in Ha Noi, a northern city in Viet Nam, a 10 µg/m³ increase in $PM_{2.5}$ was reported to increase 2.2% risk of respiratory diseases (J00 - J99) admission among children under five years on the same day of exposure (lag0) (Luong *et al.,* 2017). Meanwhile, a time-series study in HCMC reported that a 10 µg/m³ increase in $PM_{2.5}$ increased the 3.51% risk of ALRI admission at lag3 (Luong *et al.,* 2020). In Vietnam, parents often seek private clinics, doctors, or drugstores as their first choice when their children get normal diseases. If the condition is not improved, patients will be sent to hospitals. Thus, the number of hospital admissions after several days of $PM_{2.5}$ increase can be explainable.

Each 10 μg/m³ increase in $PM_{2.5}$ was also reported to increase 1.5% risk of ALRI hospital admission after two cumulative days of exposure among children under 14 years (Zheng *et al.,* 2017), 0.79% risk of lower respiratory infection (J10 – J22) after three cumulative days of exposure among children under 18 years in 18 cities of China (Pu *et al.,* 2021). However, several studies reported an insignificant association between lower respiratory diseases and acute exposure to $PM_{2.5}$ (Karr *et al.,* 2006; Karr *et al.,* 2009). The explanation for these differences could be from several reasons, such as study design, target population, the applied models for analysis, the $PM_{2.5}$ components of the study site, pathogen epidemiology, and other characteristics of the population studied.

Around 60 percent of children in this study were boys. There is a comparable result with the previous research in HCMC that the male gender was more sensitive to $PM_{2.5}$ impact than the female (Luong *et al.,* 2020). While each 10 μg/m³ increase in $PM_{2.5}$ posed a risk of hospital admission among the male group with an excess risk of 2.43% (95% CI: 0.40% ~ 4.49%), the female was insignificant. The possible explanation could be that male children are more attracted to outdoor activities than girls, leading to a high risk of exposure to outdoor pollutants (Telford *et al.,* 2016). The difference in health responses to susceptibility to air pollution between the two genders could be another reason (Clougherty, 2010). Besides, boys own other factors that facilitate a higher rate of respiratory infection, such as a smaller airway to lung (Bjornson and Mitchell, 2000), smooth muscle, vascular functions, and hormonal status (Jensen-Fangel *et al.,* 2004). A study in China reported a similar finding that $PM_{2.5}$ effects were only seen in boys (Wang *et al.,* 2021).

The percent of children in this study aged one or below was 69%. However, the impact of $PM_{2.5}$ on ALRI hospital admission among this age group was insignificant. Whereas each 10 μg/m³ increase in $PM_{2.5}$ increased 3.15% (95% CI: 0.25% ~ 6.14%) excess risk of hospital admission at lag6 among the age group from 2 to under five years. Stronger associations with $PM_{2.5}$ in older children were reported in several studies (Luong *et al.,* 2020; Wang *et al.,* 2021; Zheng *et al.,* 2017). Older children may have frequent exposure to outdoor air, thus increasing their chance of exposure to ambient air pollutants. Meanwhile, younger children could be less exposed because they were mostly kept indoors. In Vietnam, infants are usually breastfed from 12 to 24 months, which could be another protective factor from air pollution and other biological agents (Cheng *et al.,* 2013; Nhung *et al.,* 2018).

Regarding the subgroups of ALRI, nearly 67% of children in this study were hospitalized due to pneumonia (J12 – J18). This study found a positive association between $PM_{2.5}$ and pneumonia and between $PM_{2.5}$ and bronchitis at several lags. However, all associations were not statistically significant. Several studies reported the relationship between each daily 10 μg/m³ increase in $PM_{2.5}$ and pneumonia diseases among children, with the risk ranging from around 1% to more than 10% (Cheng *et al.,* 2019; Chenguang LV *et al.,* 2017; Nhung *et al.,* 2017; Nhung *et al.,* 2018; Sherris *et al.,* 2021; Wang *et al.,* 2021). Some studies revealed a contrasting result that reported a significant association between $PM_{2.5}$ and bronchitis or bronchiolitis (J20 – J21; J20-J22) (K. N. Kim *et al.,* 2020; Luong *et al.,* 2020; Zheng *et al.,* 2017).

Although collecting a health database from all three pediatric hospitals and integrating two available sources of the $PM_{2.5}$ dataset in HCMC, the study has several limitations. The first is the lack of representativeness of the $PM_{2.5}$ dataset. Using the $PM_{2.5}$ dataset from two fixed monitoring stations as a representative for the whole city may be less reliable for districts far from the monitoring stations. Applying models for estimating $PM_{2.5}$ concentrations at specific grided areas may be a better solution for subsequent studies. Secondly, due to a shortcoming of monitoring data, this study also could not take control of other air pollutants such as PM_{10}, NO_2, SO_2, and O_3, which can also affect health outcomes. Thirdly, some children's information such as weight, height, parent's occupation, average household income, and location of the family (near or far from the main street) were not fully available in the hospital records; thus, the study was unable to control them in models for more accurate results.

4. Conclusion

This study contributed additional evidence of associations between the short-term effects of $PM_{2.5}$ on respiratory diseases among children under five years old. Increasing $PM_{2.5}$ potentially poses an excess risk of ALRI hospital admission to children, especially male children and children from 2 to the under five years old. The concentrations of $PM_{2.5}$ in HCMC have been relatively high compared to the WHO's guidelines; thus, implementing mitigation measures to reduce $PM_{2.5}$ emissions from various sources is necessary. An increasing number of air quality monitoring stations that can provide real-time monitoring of particulate matter and other air pollutants should also be considered.

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