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# Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: An eight-year time series study

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ABSTRACT

*Background:* Lower respiratory diseases are the most frequent causes of hospital admission in children worldwide, particularly in developing countries. Daily levels of air pollution are associated with lower respiratory diseases, as documented in many time–series studies. However, investigations in low-and-middle-income countries, such as Vietnam, remain sparse.

*Objective:* This study investigated the short-term association of ambient air pollution with daily counts of hospital admissions due to pneumonia, bronchitis and asthma among children aged 0–17 in Hanoi, Vietnam. We explored the impact of age, gender and season on these associations.

*Methods:* Daily ambient air pollution concentrations and hospital admission counts were extracted from electronic databases received from authorities in Hanoi for the years 2007–2014. The associations between outdoor air pollution levels and hospital admissions were estimated for time lags of zero up to seven days using Quasi-Poisson regression models, adjusted for seasonal variations, meteorological variables, holidays, influenza epidemics and day of week.

*Results:* All ambient air pollutants were positively associated with pneumonia hospitalizations. Significant associations were found for most pollutants except for ozone and sulfur dioxide in children aged 0–17. Increments of an interquartile range (21.9 μg/m$^3$) in the 7-day-average level of $NO_2$ were associated with a 6.1% (95%CI 2.5% to 9.8%) increase in pneumonia hospitalizations. These associations remained stable in two-pollutant models. All pollutants other than CO were positively associated with hospitalizations for bronchitis and asthma. Associations were stronger in infants than in children aged 1–5.

*Conclusion:* Strong associations between hospital admissions for lower respiratory infections and daily levels of air pollution confirm the need to adopt sustainable clean air policies in Vietnam to protect children's health.

## 1. Introduction

A child's respiratory system is susceptible to the adverse health effects of air pollution. Children have higher breathing rates than adults (Ginsberg et al., 2005). As children grow, long-term exposure to air pollution may lead to deviations from normal growth patterns (Thurston et al., 2017). Additionally, children may spend more time outdoors engaging in physical activity and thereby inhaling higher doses of air pollutants (Gilliland, 2009).

The association between air pollution and hospitalization for acute respiratory infection (ARI) has been investigated worldwide (Barnett et al., 2005; Darrow et al., 2014; Qiu et al., 2014; Winquist et al., 2012). These studies demonstrated that daily levels of common markers of ambient air pollution such as nitrogen dioxide ($NO_2$) and particulate matter (PM) are associated with ARI. For example, Barnett et al. (2005) reported a 2.4% increase of daily hospital admissions due to pneumonia and bronchitis for a 3.8 μg/m$^3$ increase of PM with aerodynamic diameter < 2.5 μm ($PM_{2.5}$) in children, age 1–4; and a 6.0% increase of asthma hospitalization per 5.1 ppb increase of 24-h $NO_2$ in children 5–14 in New Zealand and Australia, respectively. However, evidence from Vietnam is sparse. Only one study conducted in Ho Chi Minh (HCM) (Southern Vietnam) has examined this relationship. Le et al.

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(2012) showed positive associations between ARI and both $NO_2$ and PM with aerodynamic diameter < 10 μm ($PM_{10}$) during the dry season 2003–2005, but the results were not statistically significant given the rather short series and limited statistical power (Bhaskaran et al., 2013).

The burden of ARIs such as bronchitis and pneumonia is very large among Vietnamese children. Pneumonia accounted for 11% of the total burden of diseases in children under 15 year of age in 2008 (Nhung et al., 2014), and for 11% of total deaths among children under five (data from 2014) (Nguyen et al., 2016). Pneumonia infection is the most common cause of hospital admission in Hanoi children, accounting for 54.1% of all respiratory disease-related admissions during 2007–2014(Nguyen et al., 2017). Bronchitis ranked at the second position with 19.1% of hospital admissions for respiratory diseases. Pneumonia and bronchitis were also the leading causes of prolonged hospitalization and death at the hospital during our study period. In addition, once a child develops pneumonia, proper treatment with a full course of antibiotics is vital. As a consequence, the treatment cost becomes a health economic burden for patients. The average of treatment cost for an outpatient case of pneumonia was US$71 and for severe pneumonia was US$ 235 in Pakistan (Hussain et al., 2006). The estimated treatment cost for suspected pneumonia was about US$31 in Vietnam and up to 63% of these costs were accounted for by drugs (Anh et al., 2010).

A number of risks for lower respiratory diseases have been documented in Vietnam, including environmental tobacco smoke (Suzuki et al., 2009), termination of breast feeding in early infancy (Anders et al., 2015; Hanieh et al., 2015), and ambient air pollution (Le et al., 2012). Nonetheless, these associations and the related impact on lower respiratory infections have not been studied in Northern Vietnam. Thus, it is difficult to predict the benefit of clean air policies on respiratory health in children — such as those documented in a Swiss landmark study (Bayer-Oglesby et al., 2005) — or to compare the cost-effectiveness of clean air strategies versus the provision of antibiotics.

Hanoi is a polluted city in Vietnam. The proportion of days with Air Quality Index levels at 101–200 (unhealthy level for sensitive group) ranged from 40% to 60% of total monitoring days between 2013 and 2014, according to a report from the Ministry of Natural Resources and Environment, 2014 (Ministry of Natural Resources and Environment, 2014). The report also pointed out that daily mean $NO_2$, ozone ($O_3$), sulfur dioxide ($SO_2$), and $PM_{10}$ concentrations were frequently above the World Health Organization (WHO) suggested levels. An earlier study using ground sampling measurements in Hanoi reported an annual mean of 87.1 μg/m$^3$ for $PM_{10}$, and of 36.1 μg/m$^3$ for $PM_{2.5}$ during August 1998 to July 1999(Hien et al., 2002). This study also demonstrated that wind speed, temperature and relative humidity were closely related to air pollution concentration. A recent study estimating $PM_{2.5}$ by using MODIS satellite data has shown that monthly mean values of $PM_{2.5}$ ranged from 50 μg/m$^3$ to 100 μg/m$^3$ in the Northeast region of Vietnam during the period 2009–2012(Nguyen et al., 2015). The main sources of air pollution in Vietnam are traffic vehicle exhaust, industry, and construction activities. Besides that coal mining in Quang Ninh, cement production in Hai Phong, a steel factory in Thai Nguyen and agricultural activities in Hanoi are the other local emissions in the Northeast region (Ministry of Natural Resources and Environment, 2014).

Hanoi had about 7.3 million inhabitants in 2014 with an average population density of about 2213 people/km$^2$ (Hanoi Population and Family Planning Branch, 2014). Children accounted for 28% of the total population in Hanoi. Details regarding population density and geography are presented on the map of Fig. A1. The intake fraction (an approach to quantify the link between the pollutant emissions and population exposure) of the Hanoi population may be high, as Hanoi has both high population density and vehicle volume. For example, the population density in Hoan Kiem district (central district of Hanoi) reached 38,250 people/km$^2$ in 2014 (Hanoi Population and Family Planning Branch, 2014). Therefore, the objective of this work is to investigate the short-term effects of exposure to ambient air pollution on hospital admissions due to pneumonia, bronchitis and asthma symptoms in Hanoi children under 18 years of age.

## 2. Materials and methods

### 2.1. Data source

Data on hourly means of air pollutants was obtained from two fixed monitoring stations, the Nguyen Van Cu station (2102′56.05″N, 105,052′58.59″E) and the Lang Ha station (2101′13.47″N, 105,048′24.10″E). Data were averaged by station and calendar day to provide 24-h means of $PM_{10}$, $PM_{2.5}$ and $PM_1$ (air borne particulates with an aerodynamic diameter < 1 μm), $NO_2$, nitrogen oxides ($NO_x$), $SO_2$, and carbon monoxide (CO). The daily means of the pollutants were accepted in the study if > 16 out of 24 hourly measurements were available. For $O_3$, we calculated two measures, the eight-hour maximum (the highest moving eight-hour average) and the 24-h maximum (the highest hourly mean on a given day). For these measures to be accepted, 18 out of 24 hourly measurements were required. All indicators were expressed in μg/m$^3$. Since Lang ha station used ppb as a unit for measuring $SO_2$, we converted these concentrations from ppb into μg/m$^3$ by using the WHO conversion factor, 1 ppb = 2.62 μg/m$^3$ at 25 Degree Celsius and 1013 mb (Danish Centre For Environment And Energy, n.d.).

We imputed missing daily concentration data of $PM_{10}$ and $SO_2$ in different steps. First we generated values for one-day gaps by taking the mean value of the neighboring days. To impute missing data in longer gaps, we used a regression model incorporating daily concentration data of the same pollutant from the other stations, of other pollutants from the same station, as well as daily temperature, relative humidity and wind speed. In addition, these models contained sine and cosine functions of time with a period of one year. We also considered interactions between the different variables. After these imputations, we filled any remaining one-day gaps as described in step one. Since $PM_1$ and $PM_{2.5}$ were only monitored in Nguyen Van Cu station, we used $PM_{10}$ data from Lang Ha station along with data for other pollutants to impute the missing data for $PM_1$ and $PM_{2.5}$.

Daily averages of $SO_2$ and $PM_{10}$ were generated from measurements taken from Lang Ha station (from January 2007 to May 2009) and from Nguyen Van Cu station (from June 2009 to December 2014). For other pollutants, we used data from Nguyen Van Cu station (June 2009 to December 2014).

Meteorological data were also collected for the same period from four meteorological stations, namely Lang, Ba Vi, Son Tay, and Ha Dong, and included 24-h temperature means (in $^0$C), relative humidity (in percent) and wind speed (m/s). Daily means of temperature, humidity, and wind speed were calculated by averaging values across the four stations.

Hospital admission records from January 1, 2007 to December 30, 2014 were retrieved from the computerized database of the Vietnam National Children's Hospital, Hanoi, Vietnam. In this paper, a hospital admission is defined as a hospital stay for at least one night. Readmissions within 24 h after discharge were considered as continuation of the previous hospitalization. With 1660 beds, the hospital covered the majority of all hospital admissions due to severe illnesses in Hanoi. Before being referred to a children's hospital, most children first undergo a health check at an out-patient department of the hospital. Only children with severe illness are admitted to the hospital, while the others receive prescriptive medication and are treated as outpatients. Patients with life-threatening diseases such as severe breathlessness, liver and heart failure are often directly brought to the emergency department, from where they are transferred to a specific department on the next day. A detailed description of this database, quality control and quality assurance procedures was published elsewhere (Nguyen