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Fluctuations in air pollution give risk warning signals of asthma hospitalization

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HIGHLIGHTS

- Fluctuations in air pollution may imply risks of asthma hospitalization.
- Statistical indicators of air pollution and asthma hospital admissions are associated.
- Statistical indicators based regression model can forecast asthma hospitalizations.
- Variation and skewness of are leading indicators to detect asthma admission.

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ABSTRACT

Recent studies have implicated that air pollution has been associated with asthma exacerbations. However, the key link between specific air pollutant and the consequent impact on asthma has not been shown. The purpose of this study was to quantify the fluctuations in air pollution time-series dynamics to correlate the relationships between statistical indicators and age-specific asthma hospital admissions. An indicators-based regression model was developed to predict the time-trend of asthma hospital admissions in Taiwan in the period 1998–2010. Five major pollutants such as particulate matters with aerodynamic diameter less than 10 μm (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) were included. We used Spearman's rank correlation to detect the relationships between time-series based statistical indicators of standard deviation, coefficient of variation, skewness, and kurtosis and monthly asthma hospitalization. We further used the indicators-guided Poisson regression model to test and predict the impact of target air pollutants on asthma incidence. Here we showed that standard deviation of PM_{10} data was the most correlated indicators for asthma hospitalization for all age groups, particularly for elderly. The skewness of O_3 data gives the highest correlation to adult asthmatics. The proposed regression model shows a better predictability in annual asthma hospitalization trends for pediatrics. Our results suggest that a set of statistical indicators inferred from time-series information of major air pollutants can provide advance risk warning signals in complex air pollution-asthma systems and aid in asthma management that depends heavily on monitoring the dynamics of asthma incidence and environmental stimuli.

1. Introduction

It is generally recognized that air pollution is the major environmental stimuli which may induce respiratory diseases exacerbations (Chen et al., 2012). Asthma is an allergic respiratory disease affecting millions of population worldwide. Since the growing epidemic of asthma, recent studies had taken more efforts to predict the disease progression and control (Frey et al., 2005; Thamrin et al., 2011). Several statistical methods have been applied to assess the severity and control of asthma (Que et al., 2001; Frey et al., 2011). It is known that much more clinical and basic researches are needed to understand the asthma due to the complexity of disease progression. Plausibly, effective assessment approaches are capable of predicting asthma and its various co-morbidities in the future.

Air pollutants such as particulates and oxidative chemicals are most likely associated with asthma hospital admission and emergency room visits among different age groups (Lee et al., 2003; Hwang et al., 2005; Tsai et al., 2006; Chen et al., 2012; Makra et al., 2012). It is evident that exposed to traffic-related air pollution included particulate matter with an aerodynamic diameter less than

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10 μm (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) are much likely to increase the exacerbation risk of asthma and asthma-like respiratory symptoms. Chen et al. (2006) found that air pollutant levels of O_3, SO_2, and CO were significantly associated with adult asthma admission in Taiwan. In addition, PM_{10} and O_3 contributed significantly to pediatric asthma admission (Xirasagar et al., 2006). Liao et al. (2011) found a strong association between long-term fluctuations in SO_2 time-trend and asthma admission rate. NO_2 is chemically reactive pollutant in the atmospheric environment. The nitric vapor can produce the amount of photo oxidation from automobile emissions which can induce lung damage (Yang and Omaye, 2009).

Frey et al. (2011) indicted that respiratory system has memory characteristics like many other physiological systems with complex structure. Therefore, the susceptible system can have cumulative memory effects under environmental triggers, and further cause respiratory symptoms or lung function variation associated-asthma exacerbations. The cumulative effect can occur due to the existence of lag effects which were confirmed in many epidemiological studies (Lewis et al., 2005; Bell et al., 2008; Chang et al., 2012). Thus, previous environmental stimuli are important because each specific stimulus in the past has potential to add to the cumulative effect (Frey and Suki, 2008). Therefore, the fluctuation properties in environmental stimuli may result in the short- and long-term effects in the respiratory system (Frey, 2007; Frey and Suki, 2008; Thamrin et al., 2010). Yuval and Broday (2010) indicated that meteorological and air quality variables have the statistical predictability that can implicate to exposure assessment. In light of this concept, the fluctuations in environmental triggers may imply different levels of lung failure and disease incidence (Frey et al., 2011).

The statistical techniques have been used to characterize the internal fluctuating phenomena in response to external triggers on disease exacerbations risk for describing the properties of such complexity phenomenon (Frey et al., 2005). There has been a growing interest in using statistical indicators as early warning signals of abnormal change in dynamic processes for various fields such as physiology and climate systems (Que et al., 2001; Frey et al., 2005; Dakos et al., 2008; Gorban et al., 2010; Lenton, 2011). These indicators include variance, coefficient of variation (COV), skewness, and kurtosis.

For asthma attack, statistical signatures of COV and skewness in lung ventilation were found to be correlated with the levels of disease exacerbations (Frey et al., 2005; Venegas et al., 2005). The statistical indicators in lung function measurements have been used to assess the risk of future asthma episodes, and thereby improve the assessment and management of asthma severity. Que et al. (2001) found that the spontaneous variation in airway caliber in normal subjects and asthmatic patients can be assessed over a period of minutes by measured and analyzed the variability and kurtosis of respiratory impendence. Recent studies revealed that the quantified indicators can improve the predictability and detectability in a variety of dynamical systems (Ditlevsen and Johnsen, 2010; Lenton et al., 2012; Scheffer et al., 2012).

Although recent studies have implicated an association between air pollutant and asthma exacerbations, the key link between specific air pollution and consequence impacts has not been shown. Because exacerbations of asthma are strongly related to environmental conditions, we thought that fluctuating properties in air pollution may imply advance warning signals of risk of the asthma incidence.

The purpose of this study was threefold: (1) to quantify the fluctuations in air pollutants for higher asthma epidemic areas in Taiwan, (2) to correlate the relationship between statistical indicators of air pollution and age-specific asthma hospital admissions, and (3) to predict asthma hospitalization trends by statistical indicators-based regression model. This study investigated the air pollution-associated asthma hospitalization in Taiwan in the period 1998–2010.

2. Materials and methods

2.1. Study data

Air pollution data were adopted from Taiwan Air Quality Monitoring Network (http://taqm.epa.gov.tw/taqm/en/default.aspx). There were more than seventy monitoring stations established by Taiwan Environmental Protection Administration. The hourly monitoring data were described clearly the distributions of pollutant dynamics. We selected major air monitoring stations in the highest epidemic City/County in four divided regions. Daily reading of major air pollutant levels such as PM_{10}, NO_2, SO_2, CO, and O_3 were included. We used daily average concentrations for PM_{10}, NO_2, SO_2, CO and average of daily maximum 8-h O_3 concentrations based on the air quality guideline suggested by World Health Organization (WHO) and U.S. Environmental Protection Agency (USEPA) (WHO, 2006; Weinhold, 2008).

The asthma admission records were collected from National Health Insurance database. We selected all hospitalization patients on the basis of the International Classification of Disease, Clinical Modification (ICD-9-CM) code for asthma (493). The data were recorded as number of asthma per year in terms of age, gender, and region. The annual numbers of case were divided by the year-end population to obtain the asthma hospitalization rate as the admission rate per 100,000 population based on annual population data released by Population Affairs Administration, Ministry of Interior, Taiwan.

We extracted the site-specific asthma hospitalization rate to determine the levels of epidemic in northern, eastern, central, and western Taiwan divided based on Taiwan Council for Economic Planning and Development. We estimated the annual age-specific asthma hospital admission data in the period 1998–2010. In addition, this study adopted the population–based study from Chen et al. (2006) in that the monthly age-specific asthma hospitalization rates were shown in the period 1998–2001. The asthma hospitalization were categorized into five age groups of 0–4, 5–14, 15–44, 45–64, and ≥65 yrs (Chen et al., 2006). We simplified the age group to 0–14, 15–64, and ≥65 yrs to reasonably represent the pediatric, adult and elderly asthmatics, respectively.

2.2. Statistical indicators

To investigate the relationships between statistical indicators of air pollution and age-specific asthma hospital admissions, we calculated four statistical indicators of standard deviation (SD), COV, skewness, and kurtosis (Table 1). The monthly statistical

Table 1
Equations of statistical indicator used in time-series analysis.[a]

Indicator	Equation	
Standard deviation	$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2}$	(T1)
Coefficient of variation	$\frac{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2/(n-1)}}{\bar{x}}$	(T2)
Skewness	$\frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^3}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)^{3/2}}$	(T3)
Kurtosis	$\frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^4}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)^{2}}-3$	(T4)

[a] n is sample size and $\bar{x}$ is sample mean.