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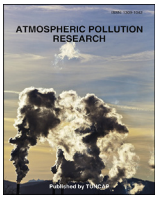

Original article

# Spatiotemporal characteristics and health effects of air pollutants in Shenzhen

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## ABSTRACT

In this study, spatiotemporal patterns and health effects in all-cause mortality of air pollutants (CO, $NO_2$, and $SO_2$) during 2013 in Shenzhen were investigated. Spatiotemporal characteristics of air quality index (AQI) and air quality are also addressed. The results show that daily averages were 10.9 $\mu g/m^3$ for $SO_2$, 39.6 $\mu g/m^3$ for $NO_2$, and 1.2 $mg/m^3$ for CO. Daily AQI ranged from 24 to 179. There were approximately 39 days of air pollution in Shenzhen. $NO_2$ was the third major air pollutant. Monthly/hourly average AQI and concentrations of $NO_2$ and $SO_2$ in the city center area were higher than in tourist areas. Annual AQI and $NO_2$ concentration were higher in western parts of Shenzhen, whereas $SO_2$ was higher in eastern portions. The lowest CO concentration was in the Luohu District. Relative risks of mortality number increased with $SO_2/NO_2$ levels. When $SO_2/NO_2$ concentration changed, female individuals were more sensitive than male individuals, and people aged older than 65 years were more affected than younger people.

## 1. Introduction

China has undergone very rapid economic growth since economic reforms in 1978. This growth has increased energy consumption, air pollution, and associated health effects (Wong et al., 2008; Hellgren et al., 2010; Cai et al., 2014; Li and Zhang, 2014). To improve air quality, protect the environment, and reduce the health burden of air pollution, the Chinese Government issued a new ambient air quality standard (GB3095-2012) (Ministry of Environmental Protection of the People's Republic of China and Administration of Quality Supervision Inspection and Quarantine (2012)) in 2012, replacing the old standard (GB3095-1996) (Ministry of Environmental Protection of the People's Republic of China and Administration of Quality Supervision Inspection and Quarantine (1996)). The new standard will be implemented incrementally nationwide by 1 January 2016. Selected cities including Beijing-Tianjin-Hebei, the Yangtze River Delta, Pearl River Delta and provincial capitals began compliance with the GB3095-2012 on 1 January 2013.

Shenzhen is in southern China, spanning 113°46′–114°37′E and 22°27′–22°52′N, with a city area of 1991.64 $km^2$ (Simons, 2003). There is a subtropical oceanic climate, with warm weather and abundant rainfall, and annual average temperature is 22.4 °C. Shenzhen is a rapidly developing city in Guangdong Province, and is located at the mouth of the Pearl River Delta adjacent to Hong Kong. It is one of the original “Special Economic Zones” that was designed to attract foreign investment, promote exports, and evaluate various economic policies. Shenzhen is exemplary of China's urban revolution and shares many environmental and social equity concerns with numerous rapidly developing cities around the world (Skoner, 2001). From 1996 to 2006, the real gross domestic product of Shenzhen increased by nearly 400%, and the

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city is now the fourth richest in China (Simons, 2003). The rapid economic development and urbanization have also given rise to a number of environmental concerns and demands on natural resources, most notably the conversion of land and accompanying impacts on air and water quality (Maziak et al., 2003; Liu et al., 2007; Chen and Jiao, 2008). As one of the first-stage cities complying with GB3095-2012 since 2013, Shenzhen has released real-time hourly monitoring concentration data of six air pollutants to the general public since 1 January 2013. Annual $SO_2$ and $NO_2$ concentrations were 9 and 42 ug/$m^3$ in 2012; and the air quality met the Grade II standard of GB3095-1996; relative to other cities in China, air quality in Shenzhen was good. Compared with previous years, however, the city is experiencing increasing air pollution (Ministry of Environmental Protection of the People's Republic of China, 2000–2013). However, there has been no comprehensive study of air pollutants ($SO_2$, $NO_2$, and CO) in Shenzhen, therefore studies on spatiotemporal patterns and health effects of those pollutants are needed.

We carried out a time-series analysis of daily/hourly air pollutant concentrations and daily number of all-cause (non-accidental) mortality during the first year (2013) of GB3095-2012 implementation in Shenzhen. Daily patterns of air quality index (AQI) and the three aforementioned air pollutants were determined, and their hourly patterns in different urban functional areas of the city were examined. Spatial distributions of the four variables were also investigated. Health effects of air pollutants on all-cause mortality were analyzed, considering various age and sex groups. The results of our analysis will help us to implement a control strategy for $SO_2$, $NO_2$, and other major pollutants in urban areas.

## 2. Methodology

### 2.1. Data sources

#### 2.1.1. Mortality data

All mortality data for the calendar year 2013 were obtained from death certificates recorded at the Shenzhen Center for Disease Control and Prevention. In the death registry, causes are coded by the International Classification of Disease, revision 10 (ICD10) (World Health Organization, 2010).

#### 2.1.2. Air pollutant monitoring data

Air quality monitoring data were provided by the China National Environmental Monitoring Center (CNEMC). Daily AQI and $SO_2$, $NO_2$, and CO concentrations were provided as daily mean values measured at 11 state-controlled monitoring stations in Shenzhen. Station locations are presented in Fig. 1. According to technical guidelines of the Ministry of Environmental Protection, these locations must not be in the immediate vicinity of traffic intersections or major industrial polluters, and should have sufficient distance from any other emission source. Thus, the monitoring data reflect general urban air quality in Shenzhen.

To determine spatiotemporal changes of hourly AQI and $SO_2$, $NO_2$, and CO concentrations, we obtained hourly monitoring data from 1 January through 30 November 2013 at two stations, and hourly AQI at all stations. The two stations were Huaqiaocheng (HQC) and Nan'ao (NA). HQC is in the city center, and was used to assess regional air quality and its variations. NA is located in the east of Shenzhen, with the sea on three sides. Most of the area around NA has the original ecology and is undeveloped, and the station data were therefore used to quantify pollution concentrations unaffected by the urban environment. Hourly air pollutant monitoring data were from the National Real-Time Air Quality Monitoring Data Publishing Platform, developed by the CNEMC.

#### 2.1.3. Meteorological data

Meteorological data (temperature, relative humidity, barometric pressure, and wind speed) were obtained from the Meteorological Bureau of Shenzhen Municipality. The data were measured at a fixed-site station in the study area, owned by that bureau. The monitoring standard of the station is consistent with that of the international World Meteorological Organization (World Meteorological Organization, 2013), and the data are representative of Shenzhen.

### 2.2. Data analysis

The objective of the data analysis was to quantify the association between daily number of mortality and air pollutant concentrations, while adjusting for weather and temporal factors in the multivariable modeling. Because number of mortality was small and typically followed a Poisson distribution (Wood, 2006; Box et al., 2013), the core analysis was a generalized additive model (GAM) with log link and Poisson error that accounted for fluctuations in daily numbers of deaths. Consistent with other time-series studies (Pope and Dockery, 2006; Zhang et al., 2012; Meng et al., 2013), we used the GAM with penalized splines to analyze the daily counts of mortality, air pollution, and covariates (meteorological factors, time trend, and day of the week).

Before conducting the model analyses, there were two steps in the procedure of the model building and model fit: development of the best base model (without a pollutant) and development of the main model (with a pollutant). The latter is achieved by adding the air pollution variables to the final cause-specific best base model, assuming a linear relationship between the logarithmic mortality number and air pollutant concentration.

First, we constructed the basic pattern of mortality number excluding the air pollution variables. We incorporated smoothed spline functions of time and weather conditions, which can include non-linear and non-monotonic links between mortality and time/weather conditions, offering a flexible modeling tool. Other covariates, such as day of the week, were also included in the basic models.

After we established the basic models, we introduced the pollutant variables and analyzed their effects on mortality. To compare the relative quality of the mortality predictions across these non-nested models, Akaike's Information Criterion (AIC) was used as a measure of how well the model fitted the data. Smaller AIC values indicate the preferred model. Briefly, we fitted the following log-linear generalized additive models to obtain the estimated pollution log-relative rate β in the study district:

$$\log[\mathrm{E(Yt)}] = \alpha + \sum_{i=1}^{q} \beta\mathrm{i(Xi)} + \sum_{j=1}^{p} \mathrm{fj(Zj, df)} + \mathrm{Wt(week)}$$

Here E(Yt) represents the expected number of mortality at day t; β represents the log-relative rate of mortality associated with an unit increase of air pollutants; Xi indicates the concentrations of pollutants at day t; Wt(week) is the dummy variable for day of the week. $\sum_{j=1}^{p} \mathrm{fj(Zj, df)}$ is the non-parametric spline function of calendar time, temperature and humidity. A detailed introduction to the GAM is given in Wood's book (Wood, 2006).

Regarding the basic models, we also did some sensitivity analysis following Welty's method (Welty and Zeger, 2005). We initialized the df as 7 df/year for time, 3 df for temperature, barometric pressure and humidity. We fitted both single-pollutants models and multi-pollutant models (models with a different combination of two or three pollutants per model) to assess the stability of pollutants' effect.