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Temporal variations in ambient particulate matter reduction associated short-term mortality risks in Guangzhou, China: A time-series analysis (2006–2016)

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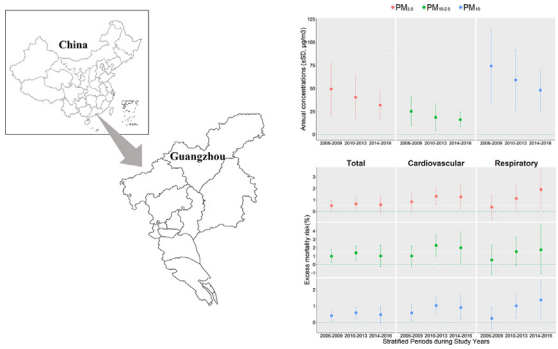
HIGHLIGHTS

- Annual averages of Ambient particulate matter (PM) continuously decreased during 2006–2016.
- Ambient PM was significantly associated with increases in mortality risks over study period.
- $PM_{2.5}$ and PM_{10} associated cardio-respiratory mortality risks were significant in recent years.
- Respiratory mortality risks in association with $PM_{2.5}$ and PM_{10} showed increases over time.

GRAPHICAL ABSTRACT



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ABSTRACT

Numerous studies have reported associations between ambient particulate matter (PM) and daily mortality; however, little is known about temporal variations in ambient air pollution associated mortality risks, particularly in developing countries with limited long time-series air monitoring data.

In present study, we assessed the associations and temporal relationships between ambient PM and daily mortality in Guangzhou, China, during 2006–2016. With this unique 11-year dataset, we related daily concentrations of PM with aerodynamic diameter < 2.5 μm ($PM_{2.5}$), between 2.5 and 10 μm ($PM_{10-2.5}$) and <10 μm (PM_{10}) to daily mortality in Guangzhou. We applied overdispersed Poisson regression with adjustment for time trend and potential confounding factors. Multiple level sensitivity analyses were conducted to examine the robustness of main results.

Between 2006 and 2016, annual concentrations of $PM_{2.5}$ decreased by 50.8% to 27.0 μg/m^3, of $PM_{10-2.5}$ by 27.6% to 16.2 μg/m^3, and of PM_{10} by 44.1% to 43.3 μg/m^3 in Guangzhou. In this study, per 10 μg/m^3 increases in mean concentrations at current day and 6 prior days of death (lag06), we observed increases in total mortality risks of

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0.55% (95% Confidence Interval (CI): 0.24%, 0.86%) for $PM_{2.5}$, 0.99% (95%CI: 0.48%, 1.50%) for $PM_{10-2.5}$, and 0.44% (95%CI: 0.22%, 0.65%) for PM_{10}. Stronger associations were observed for ambient PM on cardio-respiratory mortality and people at age ≥ 65 years. Despite drastic reductions in annual PM levels, $PM_{2.5}$ associated cardiovascular and respiratory mortality risks remained significant at 1.26% (95%CI: 0.19%, 2.35%) and 1.91% (95%CI: 0.25%, 3.60%) during 2014–2016. Further, $PM_{2.5}$ and PM_{10} associated respiratory mortality risks showed increasing trend over time (p-value = 0.03 for $PM_{2.5}$).

In summary, though ambient PM levels decreased substantially in Guangzhou in recent years, $PM_{2.5}$ and PM_{10} associated cardio-respiratory mortality risks remained significant and respiratory mortality risks even increased. Our findings provide strong rationale for continuation of ambient air pollution control effort for public health protection in the future.

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1. Introduction

Numerous epidemiological studies worldwide have reported associations between ambient air pollution and mortality and morbidity for cardio-respiratory diseases over the decades (Di et al., 2017; Samet et al., 2000; Tao et al., 2012; Zanobetti and Schwartz, 2009). With emerging evidence from global air pollution and health studies, the World Health Organization (WHO) updated the Air Quality Guidelines (AQGs) for six criteria air pollutants in 2005, aiming for air quality improvement and health risk control at a global scale (Krzyzanowski and Cohen, 2008; WHO, 2006). Among the six criteria air pollutants, particulate matter (PM) with aerodynamic diameter < 2.5 μm ($PM_{2.5}$) and <10 μm (PM_{10}) are the primary air pollutants of health concerns, and have been shown consistent and significant associations with adverse health effects (Chen et al., 2011; Franklin et al., 2007; Lee et al., 2015; Pope III et al., 2002; Wong et al., 2008).

In recent years, gradual declines in ambient air pollution levels have been achieved resulting from a series of governmental regulations and efforts on air pollution control in most Chinese cities (Bao et al., 2015; Cheng et al., 2013; Lin et al., 2014). Among these cities, air quality in Guangzhou has been improved dramatically in recent years, which is the capital city of Guangdong province locating in the center of Pearl River Delta (PRD) region. In this area, stringent air pollution control measures had been implemented for the 16th Asian Game in 2010, including transportation restrictions and emission control from industries (Ding et al., 2016; Liu et al., 2013). Further, Guangdong Air Pollution Prevention and Concentration Action Plan (GAPPCAP) was released in 2014 and under implementation since then, in which the goal of air quality improvement was specified for reducing $PM_{2.5}$ concentrations by 20% from 2012 to 2017 in Guangzhou (People's Government of Guangdong Province, 2014). Collectively, these series of efforts have resulted in large improvement in air quality in Guangzhou over the last decade (Ding et al., 2016; Jiang et al., 2015; Lin et al., 2014; Yao et al., 2012), and provided a unique opportunity for a natural experimental analysis on the temporal variations in ambient air pollution associated health risks.

Thus far, limited studies examined temporal variations in ambient air pollution concentrations and associated short-term mortality risks under air quality management framework, and the results remained inconsistent (Breitner et al., 2009; Dominici et al., 2007; Tzima et al., 2018). Dominici et al. (2007) reported the declines in PM_{10} associated total mortality risk from 1987 to 2000 in the United States, following the implementation of air pollution control policies (Dominici et al., 2007). Breitner et al. (2009) also reported reductions in mortality risks following air quality improvement between 1991 and 2002 in Erfurt, Germany (Breitner et al., 2009). However, a recent analysis from Athens, Greece during 2001–2012 reported increases in mortality risk after economic crisis in 2008, suggesting that increases in vehicular emission and consumption of heating biomass fuel might be responsible for increased toxicity of ambient PM and associated adverse health impact (Tzima et al., 2018).

We have previously reported significant increases in morality risks associated with ambient air pollution in China as well as in the PRD region (Shang et al., 2013; Tao et al., 2012; Tao et al., 2011). However, because long time-series monitoring data of air pollutants is sparse, particularly for $PM_{2.5}$ which have been routinely monitored only since 2013 in most Chinese cities, very limited research has investigated temporal variations in ambient PM associated mortality risks at a long-term scale in China. In present study, we examined temporal variations in daily mortality risks in association with ambient $PM_{2.5}$, PM with aerodynamic diameter between 2.5 and 10 μm ($PM_{10-2.5}$) and $PM_{10,}$ using a unique dataset with 11-year daily air pollution data and death counts in Guangzhou, between 2006 and 2016. We further assessed the impact of ambient size-fractioned PM on daily total and cardio-respiratory mortality, following a series of air quality improvement action in the area with overall and period-specific analyses.

2. Materials and methods

2.1. Study site description

We conducted the study in Guangzhou from 1 January 2006 to 31 December 2016, which is the capital city of Guangdong Province and located in central PRD region with total registered local residents of 14.5 million in 2017. Guangzhou undergoes a typical monsoon-influenced climate with either wet and hot months or dry and cool to mild months, with seasonal variations in wind directions.

2.2. Mortality data

We obtained daily mortality counts for the years from 2006 to 2016 from Health Statistics Information Center of Guangdong Province, including identification number, sex, age, residential address, cause of death and date of death. All mortality data were reported to the death registry system and classified by International Classification of Diseases, Revision 10 (ICD-10). Following causal categories of daily mortality data were obtained: total non-accidental mortality (ICD-10 codes A00-R99), cardiovascular mortality (ICD-10 codes I00-I99) and respiratory mortality (ICD-10 codes J00-J98) for all ages, and by age (0–64 and ≥65 years) and sex (male and female).

2.3. Environment data

Ambient air pollution data during 2006–2016 were measured at two monitoring stations, including one in Wanqingsha district (22.75°N, 113.61°E) and one in Tianhu district (23.65°N, 113.62°E) (Fig. S1), which were operated by Guangdong Environment Monitoring Center since early 2000's. Both monitoring stations were in the areas with mixed residential and commercial activities, and with distance to traffic and industrial sources. The air pollution monitors were at about 10–20 m above ground levels and regularly maintained following standard operation procedures under China national quality control assurance plan.

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