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The burden associated with ambient $PM_{2.5}$ and meteorological factors in Guangzhou, China, 2012–2016: A generalized additive modeling of temporal years of life lost

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HIGHLIGHTS

- We verified and quantified the link between multiple environmental factors and YLL.
- The generalized additive model was used to bind the environmental factors with YLL.
- $PM_{2.5}$ is an unneglectable environmental factor for disease burden in population.

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ABSTRACT

Background: Daily exposure to ambient particulate matter with aerodynamic diameter <2.5 μm ($PM_{2.5}$) increases deaths and is an important contributor to burden of disease in population. To better understand the disease burden associated with $PM_{2.5}$, we examined the effects of $PM_{2.5}$ on daily years of life lost (YLL) in Guangzhou, China.
Methods: Using Guangzhou death registry, air pollution and meteorological database, we applied generalized additive models (GAM) to the relationships between YLL and $PM_{2.5}$. We then adjusted the models for age, gender, seasonality and meteorological variables. We also conducted within-data prediction of YLL while setting 2012–2014 as baseline.
Results: Over 2 million YLLs (800,137 YLLs for females and 1,212,040 YLLs for males) were observed during 2012–2016. YLL was higher for the elderly people. Mean daily average $PM_{2.5}$ concentration was 47.3 $\mu g/m^3$. In model comparisons, the GAM with six meteorological variables (sunshine hours, relative humidity, precipitation, atmospheric pressure, wind speed, evaporation) outperformed the others. The R^2 and total deviance were 0.542 and 53.0%, respectively. Non-linear trends were observed for $PM_{2.5}$ and meteorological variables. Fitted daily YLL increased to the highest level, when $PM_{2.5}$ concentration reached 134.3 $\mu g/m^3$ and atmospheric pressure reached 99.4 kPa. Within-data prediction supported the fitted GAM, where low mean absolute percentage errors were observed.
Conclusions: Daily $PM_{2.5}$ exposure has a nonlinear effect on YLL and increased levels of $PM_{2.5}$ may lead to increased YLL. This study highlights the urge to reduce ambient $PM_{2.5}$ pollution in Guangzhou, in order to promote environmental health.

1. Introduction

For the past few years, particulate matter with aerodynamic diameter <2.5 μm ($PM_{2.5}$) has drawn increasing attention in China, partly due to a great proportion of cities (Greenpeace, 2015) with reported high levels of ambient air pollution (Rohde and Muller,

Abbreviations:: AIC, Akaike information criterion; CV_{10}, 10-fold cross-validation; DIC, deviance information criteria; GAM, generalized additive model; IQR, Inter-quartile range; MAE, mean absolute error; MAPE, mean absolute percentage error; $PM_{2.5}$, particulate matter with aerodynamic diameter <2.5μm; SD, standard deviation; VIF, variance inflation factors; YLL, years of life lost.

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2015). The 2016 China environmental report (CMEP, 2017) indicated that $PM_{2.5}$ concentrations exceeded the Chinese Ambient Air Quality Standard of 15 $\mu g/m^3$ (annual average) (GB3095-2012, 2012) and the World Health Organization's air quality guidelines (interim target 2 level) (WHO, 2005) of 10 $\mu g/m^3$ (annual average) during 2012–2016, in most cities. For instance, in 2012–2016, mean annual ambient $PM_{2.5}$ concentration was 44.3 $\mu g/m^3$ in Guangzhou (GDEPD, 2017). Guangzhou is undergoing speeding urbanization, industrialization, expanded construction and use of vehicles (Liu, 2006), all of which are the primary sources of $PM_{2.5}$ (Qian et al., 2001). Furthermore, it is surrounded by Pearl River Delta industrial region and the air quality in Guangzhou is worsened by air flow of particles from the industrial region (Wang et al., 2015; Zhang et al., 2015). Consequently, Guangzhou has been confronted by a serious ambient $PM_{2.5}$ pollution problem in recent years.

There have been consistent findings revealing that daily exposure to ambient $PM_{2.5}$ pollution increases morbidity and mortality, and also leads to growing burden of disease in population (Chen et al., 2012a; Lu et al., 2015; WHO, 2005). RW Atkinson (Atkinson et al., 2014) reported that $PM_{2.5}$ concentrations were positively associated with increased risk of hospital admission of non-accidental all-cause cases, indicating a positive impact of $PM_{2.5}$ on morbidity. Wei Huang (Huang et al., 2012) showed that an increase of $PM_{2.5}$ was related to a 2.29% increase of all-cause mortality rate in Xi'an, during 2004–2008. And in a burden of disease study, Yuming Guo (Guo et al., 2013) presented that an interquartile range increase in $PM_{2.5}$ was associated with an increase of 15.8 years of life lost (YLL, a comprehensive indicator measuring premature mortality in the global burden of disease study (Fitzmaurice et al., 2017) series) of non-accidental mortality in Beijing. In a local burden of disease study conducted in Guangzhou, Yang Jun (Yang et al., 2016) reported the positive relationship between PM_{10} (particulate matter with aerodynamic diameter <10 μm) and YLL, but failed to report the effects of $PM_{2.5}$ on YLL. Furthermore, previous studies have demonstrated that meteorological effects play a critical role in the relationship between ambient air pollution and health effects (Huang et al., 2012; Lu et al., 2015). For example, Feng Lu (Lu et al., 2015) showed that temperature might enhance the associations between PM_{10} and mortality. And Yang Jun (Yang et al., 2016) suggested that YLL may be positively associated with atmospheric pressure but failed to clarify the potential dose-response relationship between atmospheric pressure and YLL. Thus, the ecological dose-effects of meteorological conditions on health outcome still need further study.

To the best of our knowledge, there have not been any temporal burden of disease study in Guangzhou focusing on the relationship between daily exposure to $PM_{2.5}$ and excess YLL. Yet, reliable evaluation of the disease burden related to $PM_{2.5}$ exposure is crucial to support evidence-based environmental policy for the air-pollution-beset city of Guangzhou. Besides, meteorological changes may also have effects on excess YLL, and we argue that meteorological effects should also be incorporated in evaluation of the relationship between $PM_{2.5}$ and YLL.

In this paper, we present a generalized additive model (GAM) exploring temporal relationships between daily excess YLL, and various variables including air pollution and meteorological conditions in Guangzhou. The goal is to unfold the crucial relationships that can be used to improve the understanding of the daily disease burden mechanisms, enhance the forecast accuracy of daily burden under $PM_{2.5}$ exposure and different meteorological conditions, and provide effective measures for mitigating the disease burden. The study complies with the Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD) statement (Collins et al., 2015).

2. Material and methods

2.1. Study area and population

Guangzhou (23°07′ North, 113°15′ East), being a port on the Pearl River, is located in southern China. It is comprised of 11 districts, with a high population density of 14.04 million people (Worldpopulationreview, 2018) residing in a total area of 7434 km^2. The city has a marine subtropical monsoon climate, which features warm weather, abundant precipitation and sunshine, a long summer and a short frost period (Li et al., 2014). During the period from 2012 to 2016, Guangzhou's annual average temperature was 21.8 °C, with an average relative humidity of 79.74%, and an average annual precipitation of 2537 mm.

2.2. Data collection

2.2.1. Mortality data

Daily mortality data (excluding accidental deaths) from 1 January 2012 to 18 March 2016 were obtained from the death registry system at the Guangzhou Center for Disease Control and Prevention. All deaths were registered residents of urban areas of Guangzhou city. Causes of mortality were coded according to the International Classification of Diseases, 10th Revision (ICD-10) (WHO, 2015). The death registry data included daily counts of non-accidental mortality (ICD-10: I00–I99, G46, J00-J99), for age-specific groups (0-, 1-, and 5-year age groups up to $\geq$ 85 years) and gender-specific groups (female and male). Data were also classified by broader age group (< 65 years and $\geq$ 65 years) to compare with similar studies (Guo et al., 2013). Detailed information on death registry system and control of data quality can be found elsewhere (Lu et al., 2015).

2.2.2. YLL data

The daily mortality data were used in calculating age-gender-specific daily YLL. YLL was calculated with formula *(1)* (Hay et al., 2017), where the number of fatal cases *(d)* for a specific cause *(c)* of premature death at age *(a)* was multiplied by the remaining life expectancy *(e)* at age $\tilde{a}$. Life expectancy was estimated using life table approach. We adopted Coale-Demeny West model (Coale et al., 2013) life table in revising age-gender-specific mortality. Life expectancy at birth was estimated as 82.5 years for females, and 80 years for males (Table A.1).

$$YLL = \sum_{c} d_c^{a,\, s} \times e_c^{\tilde{a},\, s} \qquad (1)$$

2.2.3. Ambient $PM_{2.5}$ data

Daily $PM_{2.5}$ data for 2012–2013 were obtained from the U.S. Consulates monitoring system in Guangzhou (US Consulate, 2018) while data for 2013–2016 were obtained from the Guangzhou Environmental Monitoring Center. Different sources were used because historical $PM_{2.5}$ data were not officially available before 2013 (CMEP, 2012). Previous studies showed that, $PM_{2.5}$ concentrations from the U.S. Consulates were consistent with those obtained from the environmental monitoring center (Liu et al., 2013; San Martini et al., 2015). City-level daily concentrations of $PM_{2.5}$ were calculated by averaging daily mean concentrations measured from 11 state-controlled monitoring stations (CMEP, 2012). The twelve fixed monitoring sites (including the consulate site) were distributed in different part of the urban area of Guangzhou (Appendix Figure A.1). All monitoring stations are located in the central urban area, where the main source of air pollution is traffic.