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Shipping pollution emission associated with increased cardiovascular mortality: A time series study in Guangzhou, China☆

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A B S T R A C T

Substantial evidence has linked short-term exposure to ambient fine particulate matter ($PM_{2.5}$) with increased cardiovascular mortality, however, the specific chemical constituent and emission source responsible for this effect remained largely unclear. A time series Poisson model was employed to quantify the association of cardiovascular mortality with two sets of shipping pollution emission: nickel (Ni), vanadium (V) (the indices of shipping emission) and estimated shipping emission using a source apportionment approach in Guangzhou, China in 2014. We observed that Ni, V, and estimated shipping emission in $PM_{2.5}$ were associated with increased cardiovascular mortality, an inter-quartile range (IQR) increase in lag_2 Ni was associated with 4.60% (95% CI: 0.14%, 9.26%) increase in overall cardiovascular mortality, and 13.35% (95% CI: 5.54%, 21.75%) increase in cerebrovascular mortality; each IQR increase of lag_1 V was correlated with 6.01% (95% CI: 1.83%, 10.37%) increase in overall cardiovascular mortality, and 11.02% (95% CI: 3.15%, 19.49%) increase in cerebrovascular mortality; and each IQR increase in lag_1 shipping emission was associated with 5.55% (95% CI: 0.78%, 10.54%) increase in overall cardiovascular mortality, and 10.39% (95% CI: 1.43%, 20.14%) increase in cerebrovascular mortality. The results remained robust to adjustment for $PM_{2.5}$ mass and gaseous air pollutants. This study suggests that shipping emission is an important detrimental factor of cardiovascular mortality, and should be emphasized in air pollution control and management in order to protect the public health in Guangzhou, China.

1. Introduction

Exposures to airborne suspended fine particles ($PM_{2.5}$) have been associated with increased daily mortality and morbidity (Achilleos et al., 2017; Chung et al., 2017; Lin et al., 2016b). Results from these previous studies have served as important evidence for the formulation and revision of ambient air quality guidelines/standards (Ministry of Environmental Protection of China, 2012; World Health Organization, 2006).

Currently, only the mass concentration of $PM_{2.5}$ is regulated across various countries (Lin et al., 2016a). Although these regulations have been useful to protect the population health (Guo et al., 2016; Tian et al., 2013), the more targeted objective is to identify more specific pollution emission sources that are more relevant to human health in order to formulate more specific air pollution control policies, we therefore propose the concept of “precision environment pollution control and management”, which should be the direction of future air pollution control and related policy

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making.

Furthermore, the magnitudes of the health effects of ambient $PM_{2.5}$ have been reported to be different greatly from one area to another (Chen et al., 2017; Lin et al., 2016b; Liu et al., 2017), which might be partly due to the differences in chemical constituents and pollution sources (Ming et al., 2017; Samoli et al., 2016). A recent literature review (Lu et al., 2015) and a multi-city study in China (Chen et al., 2012) reported an interesting finding that the lower the annual average concentration, the higher health effect of PM pollution, and the highest health effect was observed in Guangzhou, an important port city in China, the underlying reasons, however, remained largely unknown.

In a few port cities, shipping emission-associated air pollution has been an important environmental issue, and has been suggested to be responsible for some of the health effects of PM pollution (Liu et al., 2016). For example, one study from New York reported that shipping emission was particularly harmful to cardiovascular system using nickel (Ni) in $PM_{2.5}$ as an indicator (Lippmann et al., 2006). One study examined the health benefits of a mandated policy to use low sulfur fuels in Hong Kong in 1990, and found that significant mortality reduction was associated with ambient sulfur dioxide, vanadium (V) and nickel (Hedley et al., 2002; Lippmann et al., 2006). And a time series study reported that ship emission (using Ni and V as an index) was significantly associated with increased cardiovascular morbidity in Hong Kong (Tian et al., 2013). As a port city similarly affected by shipping pollution emissions, we hypothesized that there was a positive association between the shipping-associated air pollution and cardiovascular mortality in Guangzhou, China.

We therefore conducted this study to explore the associations of daily concentrations of Ni and V with mortality from overall and specific cardiovascular diseases, after adjusting for other air pollutants; we also did a source apportionment to estimate the fraction of shipping emission in ambient $PM_{2.5}$, and examined its association with mortality in Guangzhou, China.

2. Materials and methods

Guangzhou is an important port city in south China. The residents in Guangzhou were selected as the study population in this study. There was a total of 13.1 million residents in the city in 2014. The city has a humid and subtropical climate affected mainly by the Asian monsoon, the annual mean temperature was 19–24 °C, and the mean relative humidity was between 69% and 83%.

2.1. Mortality data

The daily mortality data were retrieved from death registry system in Guangzhou for the year of 2014. In Guangzhou, it is legally requested to report all deaths to the death registry system. The cause of death categorized by the 10th Revision of the International Classification of Diseases (ICD-10) was used to abstract the daily count of overall cardiovascular mortality (CVD, ICD10: I00–I99), as well as specific cardiovascular diseases, including ischemic heart diseases (IHD, ICD10: I20–I25), acute myocardial infarction (AMI, ICD10: I21), and cerebrovascular diseases (CBD, ICD10: I60–I69).

2.2. Air pollution and meteorology data

We measured daily $PM_{2.5}$ chemical species data at one air monitoring station in the South China Institute of Environmental Sciences located in central Guangzhou. Details of the chemical analysis and source apportionment have been described elsewhere (Tao et al., 2016). Briefly, the $PM_{2.5}$ chemical constituents were measured every three days in 2014 and were used in this analysis. These constituents included organic carbon (OC), elemental carbon (EC), five water-soluble ions ammonium (NH_4^+), sulfate (SO_4^{2-}), (nitrate (NO_3^-), sodium ions (Na^+), chloride (Cl^-), K^+, Mg^{2+} and Ca^{2+}, and F^-) and 21 trace elements (Al, Ti, K, S, Co, Pb, Si, Rb, Mg, Ca, Na, V, Fe, Cr, Cu, Zn, Mn, Ba, Cl, Sb, and Ni). Ni and V were used as the element tracers of shipping emissions in this study as they were the main metallic impurities from residual fuel oil used in ocean going ships in Guangzhou (Zhong et al., 2013).

Source apportionment analysis was performed using Positive Matrix Factorization Model proposed by the US Environmental Protection Agency (Tao et al., 2016). Six major emission sources were finally identified: traffic emissions, soil dust, shipping emissions, coal combustion, secondary sulfate and biomass burning, and secondary nitrate and chloride. The identified shipping emission source was used in the subsequent analysis.

We also obtained daily mean concentrations of other air pollutants, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) in Guangzhou (Lin et al., 2016b). The daily mean concentrations across the 11 air monitoring stations (Fig. 1) were calculated and considered as potential confounders in the models. Daily mean temperature (°C) and relative humidity (%) were provided by the Guangdong Climate Center.

2.3. Statistical analysis

We examined the association between air pollutants and CVD mortality using a generalized additive Poisson model (GAM). To control for the nonlinear time varying variables, such as long-term trend, seasonal pattern and meteorological factors, we used penalized smoothing splines. *A priori* model specification and the degree of freedom (df) were selected based on previously published studies (Kan et al., 2007; Zhao et al., 2017). Specifically, we used a df of 6 per year for time trend, a df of 6 for the moving average of the same day and previous three days' mean temperatures (Temp03), a df of 3 for the current day's humidity. We used dummy variables to adjust for day of the week (DOW) and holiday, the model can be specified as:

$$\log[E(Y_t)] = \alpha + s(t, df = 6/year) + s(Temp03, df = 6) + s(Humidity, df = 3) + \beta_1{}^{*} DOW + \beta_2 * PH$$

Where $E(Y_t)$ is the expected daily number of cardiovascular mortality on day t, α is the intercept, s() is the smoothing function based on penalized splines, t represents time for the purpose of adjusting for seasonality and long-term trends, and β_1 and β_2 are regression coefficients.

We examined the short-term association of CVD mortality with Ni, V and shipping emission on the current day and previous five days (lag_0-lag_5). We also performed analyses stratified by sex, age and season; age was classified into two groups: young (<65 years) and old group (≥65 years) (Chen et al., 2012). Season was categorized into warm and cold seasons, warm season was defined as April to September, and cold season was October to March.

A few sensitivity analyses were conducted, we used mortality in the central area of Guangzhou, which was geographically close to the component monitoring station (Fig. 1). Besides the single-pollutant models, we also used two-pollutant models of $PM_{2.5}$ mass and the gaseous air pollutants (SO_2, NO_2, and O_3). For the two-pollutant models, we used the mean concentrations of the pollutants in both the 11 general stations and the three stations in central Guangzhou (Fig. 1). Considering the possible over-dispersion of the daily mortality, we also examined the association by conducting the statistical models with a quasi-Poisson link.

The effect estimate was expressed as excess risk (ER) in daily