Estimating health burden and economic loss attributable to short-term exposure to multiple air pollutants in China

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Abstract

Background Existing studies focused on the evaluation of health burden of long-term exposure to air pollutants, whereas limited information is available on short-term exposure, particularly in China.

Methods Air pollutants concentrations in 338 Chinese cities in 2017 were used to estimate the air pollutants related health burden which was defined as premature mortalities from all-cause, cardiovascular and respiratory disease as well as hospital admissions (HAs) for cardiovascular and respiratory disease. Log-linear model was used as the exposure-response function to estimate the health burden attributable to each air pollutant. The value of statistical life and cost of illness methods were used to estimate economic loss of the premature mortalities and HAs, respectively.

Results The national all-cause premature mortalities attributable to all air pollutants was 1.35 million, accounting for 17.2% of reported deaths in China in 2017. Among all-cause premature mortality, contributions of PM₁₀, SO₂, NO₂, CO, and O₃ were 16.3%, 9.6%, 28.9%, 22.2% and 23.0%, respectively. The national cardiovascular and respiratory premature mortalities were 0.78 and 0.21 million, respectively. About 6.79 million cardiovascular and respiratory disease HAs were attributed to short-term exposure to PM₁₀, SO₂, NO₂, and O₃. The economic loss of the overall health burden was 2057.66 billion Yuan, which was equivalent to 2.5% of the national GDP in 2017.

Conclusions The health burden and economic loss attributable to short-term exposure to ambient air pollutant are substantial in China. It suggested that the adverse health effects attributable to short-term exposure to air pollutant should not be neglected in China.

1. Background

Due to the rapid development of industrialization and urbanization, many cities in China have been experiencing severe air pollution. The major air pollutants in China are PM_{2.5} (particles $\leq 2.5\mu\text{m}$ in aerodynamic diameter), PM₁₀ (particles $\leq 10\mu\text{m}$ in aerodynamic diameter), sulfur dioxide (SO₂), nitrogen oxide (NO₂), carbon monoxide (CO), and ozone (O₃). In recent years, adverse health effects of these air pollutants have attracted great public attention in China, and numerous studies have concentrated on estimating the health burden and economic loss associated with air pollution[1–3].

Health burden associated with air pollution can be divided into acute and chronic health burden caused by long-term and short-term exposure, respectively. Existing studies typically focus on the chronic health burden attributable to long-term exposure to air pollutants in China [2–4]. No study has been conducted to estimate the health burden of short-term exposures of PM₁₀, SO₂, NO₂, CO and O₃ at national level, and only one study has estimated the premature mortality attributable to short-term exposure to PM_{2.5} [5].

However, the short-term exposure to air pollutants may also be associated with enormous health burden. For instance, Chen et al. reported that the contributions of short-term exposure to above six air pollutants ranged from 6.5% to 25.7% in all-cause mortality, from 6.5% to 24.9% in respiratory mortality, and from

7.0% to 29.5% in cardiovascular mortality in China [6]. Lu et al. found that the overall all-cause premature mortality due to short-term exposure to NO₂, O₃ and PM₁₀ with the values ranged from 13,217 to 22,800 in the Pearl River Delta region in China in 2013 [7]. In addition, as the health burden associated with air pollution directly reduces the supply of labor [8] and increases costs of medical treatment [3], it will have a negative impact on the economy. Although substantial economic loss of health burden attributable to long-term exposure to air pollutant have been confirmed in many studies [1, 3], economic loss to short-term air pollution exposure are not clear in China.

This study comprehensively investigated the health burden and economic loss attributable to short-term exposure to PM₁₀, SO₂, NO₂, CO, and O₃ in China in 2017. We are going to (1) estimate the premature deaths and HAs attributable to short-term exposure to above ambient air pollutants for 338 cities in China; (2) to evaluate the economic loss of premature death and HA using the value of statistical life (VSL) method and cost of illness (COI), respectively. The results will provide a scientific basis for the policy maker to formulate relevant policies for air pollution control projects.

2. Data And Methodology

2.1 Data

2.1.1 Study area, air pollutants and population

338 cities covering 31 provinces of mainland China were included in the study. Data on ambient air pollutants (PM₁₀, SO₂, NO₂, CO, and O₃) concentrations in these cities from 1st January 2017 to 31st December 2017 were obtained from the website of the China National Environmental Monitoring Center (<http://113.108.142.147:20035/emcpublish/>). The city-specific population was derived from the National Statistical Yearbook in each Province and the Statistical Bulletin of National Economic and Social Development in each city.

2.1.2 Daily cause-specific health endpoint incidence rate

The health endpoints were defined as “all-cause mortality”, “cardiovascular disease mortality”, “respiratory disease mortality”, “cardiovascular disease HAs”, and “respiratory disease HAs” in this study. The city-specific annual all-cause mortality rates in 2017 were obtained from the National Statistical Yearbook in each Province and Statistical Bulletin of National Economic and Social Development in each city (Fig. S1).

The annual cardiovascular and respiratory disease mortality rate for each city was calculated by multiplying the annual all-cause mortality rate by the proportion of corresponding cause, which was shown in Fig. S2-S3. The proportions of cardiovascular disease and respiratory disease to the all-cause mortality were obtained from the China Health and Family Planning Statistics Yearbook. The annual HA

incidence rates for cardiovascular and respiratory disease were fixed at 873.52 and 810.22 per 10⁵ population for all cities in China, respectively [9].

The monthly cause-specific mortality rate was calculated by multiplying the annual cause-specific mortality rate by the proportion of mortality rate in different months. The province-specific proportions of mortality rates in different months were obtained from the Six National Population Census (<http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm>). The monthly mortality rate was evenly converted into daily rate, and the annual HA incidence rate was evenly converted into daily rate.

2.1 Health burden assessment

We used the log-linear exposure-response function to estimate the health burden attributable to short-term exposure to air pollutant [10–13]. Specifically, the health burden for each health endpoint was calculated as follows,

(1)

where H_{ij} denotes the health burden j attributed to air pollutant i , and BI_j is the daily baseline incidence rate of health endpoint j , and EP is the exposure population. f is the exposure-response function for health endpoint j exposed to air pollutant i , which is an estimate of the percentage increase in daily health endpoint and can be obtained from recent epidemiological studies [14–20] (Lai, 2013 #2600; Ma, 2016 #2675) (Table 1). C_i is the daily concentration of air pollutant i , and C_{0i} is the daily threshold concentration for air pollutant i which is assumed to be zero in our study [6, 21–23]. Because the study on CO-related cardiovascular and respiratory HAs did not exist in China, we did not estimate HAs attributed to CO.

Table 1 Percent increase in cause-specific health endpoints along with their 95% confidence intervals for each pollutant

2.2 Estimation of economic loss

We applied the VSL and COI methods to estimate the economic loss due to mortality and HA. The provincial VSL and COI were estimated and used for corresponding cities in that province.

The VSL is mainly determined by the GDP per capita and consumer price index (CPI) in each year. $VSL_{k,2017}$ is the adjusted VSL in province k in 2017 and can be calculated by the Eq. (2),

$$VSL_{k,2017} = VSL_b \times G_{k,2010} G_{2010}^{\beta} \times 1 + \% \Delta P_k + \% \Delta Y_k^{\beta} \quad (2)$$

where VSL_b is the reference value of VSL in Beijing in 2010 which is 1.68 million Chinese Yuan [24]. β is the income elasticity of health cost, which equals to 0.8 as recommended by OECD [25]. G_{2010} is the GDP

per capita in Beijing in 2010. $G_k, 2010$ is the GDP per capita in province k in 2010. $\% \Delta P_k$ and $\% \Delta y_k$ are the percentage increase/decrease in CPI and GDP per capital in the province k during 2010 to 2017. These data can be obtained from the China Statistical Yearbook (<http://data.stats.gov.cn/easyquery.htm?cn=C01>).

The COI for cardiovascular disease and respiratory disease hospitalization per case was estimated by the Eq. (3) [7],

$$COI_j = COH_j + DGDP \times T_j \quad (3)$$

where COH_j is the average medical treatment cost for a disease j for each case, $DGDP$ is the GDP per capita per day, T_j is the average labor time lost due to disease j for each case, COI_j is the average cost of illness of hospitalization for a disease j for each case. According to the China Health and Family Planning Statistics Yearbook, the medical cost of hospitalization for cardiovascular disease and respiratory disease has been fixed for all cities at 10669.58 Yuan and 5863.57 Yuan, respectively; and the labor time lost for cardiovascular disease and respiratory disease hospital admission was 9.51 days and 7.71 days for all cities, respectively [9]. The daily average of per capita GDP of each province were obtained from the National Statistical Yearbook in each Province.

The economic loss of health endpoint j attributable to exposure to air pollutant i ($HELi,j$) was calculated according to Eq. (4),

$$HELi,j = Hli,j \times EC_j \quad (4)$$

where Hli,j is the health burden defined in Eq. (1) and EC_j is the economic loss per case for health endpoint j . The detail provincial economic loss per case of different health endpoints are shown in Table S1.

3. Results

3.1 Air pollutant exposure assessment

Spatial distribution of the study population and average annual air pollutant concentrations in 338 cities across China in 2017 are shown in Fig. 1. It is obvious that all air pollutant concentrations tended to be higher in the northern regions than in the southern regions. The overall average annual concentrations of PM_{10} , SO_2 , NO_2 , CO , and O_3 across all cities were $79.73 \pm 16.14 \text{ ug/m}^3$, $18.14 \pm 10.77 \text{ ug/m}^3$, $30.23 \pm 10.65 \text{ ug/m}^3$, $0.96 \pm 0.29 \text{ mg/m}^3$, and $94.25 \pm 12.86 \text{ ug/m}^3$, respectively. The provinces which had the highest PM_{10} , SO_2 , NO_2 , CO , and O_3 concentrations were Xinjiang ($127.10 \pm 76.38 \text{ ug/m}^3$), Shanxi ($54.81 \pm 14.54 \text{ ug/m}^3$), Hebei ($46.19 \pm 10.00 \text{ ug/m}^3$), Shanxi ($1.54 \pm 0.30 \text{ mg/m}^3$) and Shandong ($109.95 \pm 4.65 \text{ ug/m}^3$), respectively. There were 190 (56.2%), 65 (19.2%), and 3 (0.9%) cities which did not meet the Chinese National Ambient Air Quality Standard (CNAAQs) on PM_{10} (70 ug/m^3), NO_2 (40 ug/m^3), and SO_2 (60 ug/m^3), respectively.

Fig. 1. Spatial distribution of population and annual average air pollutant concentrations in 338 cities in China in 2017: (a) Population, (b) PM₁₀, (c) SO₂, (d) NO₂, (e) CO, and (f) O₃.

3.2. Premature mortality attributable to air pollutant

The all-cause premature mortality attributed to short-term air pollutant exposure in 338 Chinese cities are shown in Fig. 2. The national premature mortality attributable to all air pollutants in China was 1.35 (95% CI: 1.02 - 1.65) million, accounting for 17.2% of reported deaths in China in 2017. The five provinces with the highest all-cause premature mortality were Shandong [131.33 (95% CI: 98.41 - 160.61) thousand], Henan [109.59 (95% CI: 82.35 - 134.12) thousand], Hebei [103.97 (95% CI: 77.97 - 126.87) thousand], Jiangsu [89.22 (95% CI: 67.28 - 108.59) thousand], Guangdong [77.64 (95% CI: 58.77 - 94.39) thousand], which contributed 9.7%, 8.1%, 7.7%, 6.6%, and 5.7% of the national all-cause premature mortality, respectively. In the national premature mortality, NO₂ contributed 28.9% [0.39 (95% CI: 0.31 - 0.45) million], O₃ contributed 23.0% [0.31 (95% CI: 0.23 - 0.39) million], CO contributed 22.2% [0.30 (95% CI: 0.24 - 0.37) million], PM₁₀ contributed 16.3% [0.22 (95% CI: 0.15 - 0.28) million], and SO₂ contributed 9.6% [0.13 (95% CI: 0.09 - 0.16) million]. The highest premature mortalities attributable to PM₁₀ [23.20 (95% CI: 16.46 - 30.68) thousand], SO₂ [14.91 (95% CI: 9.94 - 18.22) thousand], NO₂ [36.99 (95% CI: 29.06 - 42.27) thousand], CO [27.27 (95% CI: 21.22 - 33.23) thousand], and O₃ [28.98 (95% CI: 21.73 - 36.22) thousand] were all observed in Shandong province.

The city-specific contributions of air pollutants to all-cause mortality are shown in Fig. 3. The all air pollutants contribution to all-cause mortality ranged from 7.3% (Nyingchi in Tibet) to 28.8% (Lvliang in Shanxi province) in 338 cities in 2017. The province which had the highest contributions (26.0%) of all air pollutants was Shanxi province. In addition, the provinces with contribution of all air pollutants more than 20% were Hebei (25.8%), Tianjin (23.1%), Henan (22.2%), Shandong (21.8%), Xinjiang (21.6%), and Shaanxi (21.5%) province. The average contributions of PM₁₀, SO₂, NO₂, CO, and O₃ to all-cause mortality across China were 2.6%, 1.6%, 4.8%, 3.7% and 3.8%, respectively. The provinces had the highest average contributions of PM₁₀, SO₂, NO₂, CO, and O₃ to all-cause mortality were Xinjiang (4.7%), Shanxi (5.2%), Hebei (6.9%), Shanxi (5.9%), and Henan (4.3%), respectively.

The national cardiovascular and respiratory disease premature mortalities attributable to all air pollutants were 0.78 (95% CI: 0.51 - 1.00) million and 0.21 (95% CI: 0.13 - 0.29) million, which were 19.4% and 19.6% of corresponding cause-specific death in China in 2017. The average contributions of PM₁₀, SO₂, NO₂, CO, and O₃ to national cardiovascular disease premature mortality were 21.8% [0.17 (95% CI: 0.12 - 0.22) million], 6.4% [0.05 (95% CI: 0.04 - 0.06) million], 24.4% [0.19 (95% CI: 0.15 - 0.21) million], 25.6% [0.20 (95% CI: 0.14 - 0.24) million] and 21.8% [0.17 (95% CI: 0.07 - 0.28) million], respectively. And the national premature mortality for respiratory disease associated with NO₂, PM₁₀, O₃, CO, and SO₂ were 57.25 (95% CI: 42.95 - 67.99) thousand, 50.77 (95% CI: 35.63 - 66.81), 45.67 (95% CI: 22.83 - 69.50) thousand, 31.55

(95% CI: 8.97 - 53.91) thousand, and 22.26 (95% CI: 16.70 - 29.68) thousand, respectively. The spatial distributions of premature mortalities from cardiovascular disease and respiratory disease were similar to the distribution of all-cause premature mortality (Fig. S4-S5).

3.3. HAs attributable to air pollutant

The air-pollutant related HAs in 31 provinces are shown in Table S2 and Table S3. The absence of CO contributions in respiratory and cardiovascular disease HAs would lead to the underestimated total air-pollutant related HAs. The national cardiovascular disease and respiratory disease HAs attributable to the four air pollutants (PM₁₀, SO₂, NO₂, and O₃) were 2.58 (95% CI: 1.22 - 3.92) million and 4.21 (95% CI: 2.77 - 5.66) million, respectively. The national cardiovascular disease HAs attributable to PM₁₀, SO₂, NO₂ and O₃ were 0.37 (95% CI: 0.17 - 0.56) million, 0.53 (95% CI: 0.37 - 0.66) million, 0.20 (95% CI: 0.11 - 0.30) million, 1.48 (95% CI: 0.57 - 2.39) million, respectively. For the national respiratory disease HAs, the contributions of PM₁₀, SO₂, NO₂, and O₃ were 11.2% [0.47 (95% CI: 0.21 - 0.73) million], 21.4% [0.90 (95% CI: 0.67 - 1.14) million], 12.1% [0.51 (95% CI: 0.30 - 0.72) million], 55.3% [2.33 (95% CI: 1.59 - 3.07) million], respectively.

3.4 Economic loss

The national economic loss due to the air pollution related premature deaths and hospital admissions in 2017 was 2057.66 (95% CI: 1537.35 - 2523.12) billion Yuan, which was 2.5% of the total GDP in China. In the national economic loss, premature deaths accounted for 1995.73 (95% CI: 1502.50 - 2434.48) billion Yuan, approximately 97.0% of the national economic loss. The national economic loss attributable to PM₁₀, SO₂, NO₂, CO, and O₃ were 319.66 (95% CI: 224.83 - 424.40) billion Yuan, 195.28 (95% CI: 129.65 - 240.15) billion Yuan, 604.02 (95% CI: 473.66 - 691.64) billion Yuan, 440.43 (95% CI: 342.82 - 536.84) billion Yuan and 496.24 (95% CI: 364.40 - 628.12) billion Yuan, respectively. The five provinces with the highest total economic loss (premature deaths and hospital admissions) were Shandong [235.77 (95% CI: 175.64 - 289.51) billion Yuan], Jiangsu [202.53 (95% CI: 151.90 - 247.45) billion Yuan], Guangdong [144.93 (95% CI: 108.81 - 177.17) billion Yuan], Henan [137.98 (95% CI: 102.77 - 169.88) billion Yuan], Hebei [135.38 (95% CI: 100.78 - 166.05) billion Yuan] province (Table S4).

Fig. 2. Spatial distribution of the premature deaths in all-cause mortality in 338 cities in China in 2017: (a) all air pollutants, (b) PM₁₀, (c) SO₂, (d) NO₂, (e) CO, and (f) O₃.

Fig. 3. The contributions of air pollutants in all-cause mortality in 338 cities in China in 2017: (a) all air pollutants, (b) PM₁₀, (c) SO₂, (d) NO₂,

(e) CO, and (f) O₃.

4. Discussion

In this study, we firstly estimated premature mortalities and HAs attributed to short-term ambient air pollutants exposure and corresponding economic loss in 338 Chinese cities in 2017. About 1.35 million premature deaths were estimated attributable to short-term air pollutants exposure, accounting for 17.2% of total deaths in China in 2017. About 6.79 million HAs were attributable to short term exposure to PM₁₀, SO₂, NO₂, and O₃. The national economic loss of mortality and HAs associated with short-term exposure to air pollutants was 2057.66 billion Yuan, which was equivalent to 2.5% of the total GDP in China in 2017. To the best of our knowledge, this is the first study providing a comprehensive assessment of acute health burden and its economic losses attributable to short-term exposure to PM₁₀, SO₂, NO₂, CO, and O₃ in China. This study would fill an important gap in the assessment of acute health burden associated with air pollution in China.

Our findings suggested that the health burden and economic loss attributable to short-term air pollutants exposure are substantial. To date, few studies have been conducted on health burden attributable to short-term exposure to air pollutants in China. The possible reason is that the exposure-response coefficients of short-term exposure to air pollutants are far less than those of long-term exposure [14–18, 26–28]. However, China is the most polluted area and have the largest population worldwide so that the ultimate health burden may not negligible[6, 7]. In our study, we found approximately 1.35 million premature deaths and 6.79 million HAs attributable to short-term exposure to air pollutants in China, respectively. We should not ignore such dramatic health burden and economic losses attributed to short-term air pollution exposure.

The spatial variation of the health burdens is of great significance for the formulation of air pollution control policies in different cities. To reduce the health impacts caused by air pollution, the Chinese government has designated thirteen regions as priority regions for air pollution control in the National Air Pollution Prevention and Control Plan in the 12th Five-Year Plan (2011–2015) [29]. Cities with high premature deaths and hospital admissions were mainly located in the priority control regions such as the Pearl River Delta region [7] and the Beijing-Tianjin-Hebei region [30]. However, we also found that some cities in Xinjiang, Henan, and Anhui provinces also had heavy health burden, which were not in the priority regions mentioned above. The possible reason is that these provinces have higher air pollutant concentrations or huge population. From the perspective of health protection, the additional air pollution control measures in non-priority regions also should be strengthened. In addition, the Guangdong province located in the coastal region with low air pollutants concentrations also had a huge health burden possibly due to a large population. All these suggested that it is of great importance for each city to continue to draw up pertinent air pollutant control policies to further reduce the health burden caused by air pollution.

We found that the health burden associated with gaseous pollutants (SO_2 , NO_2 , CO , and O_3) are significantly greater than that of PM_{10} . In recent years, the particulate matter (PM) is typically considered to be the primary air pollutants, which contributes the most health impacts to Chinese population [31]. There are many studies focused on estimating the PM-related health burden [1, 3, 32]. However, we observed that NO_2 , not PM_{10} , contributed the most to the premature mortality among the five air pollutants in our study. In addition, the contributions of CO and O_3 to premature mortality were also significantly greater than that of PM_{10} . For the HAs, the contributions of O_3 , NO_2 and SO_2 were also significantly greater than that of PM_{10} . Similarly, Chen et al. [6] found that the highest contribution to premature mortality was made by NO_2 across China. Lu et al. [7] also found that the contributions of NO_2 and SO_2 to all-cause mortality, outpatient visits and HAs were significantly greater than that of PM_{10} in the Pearl River Delta region in China. The possible reason is that the exposure-response coefficients of NO_2 , SO_2 , CO , and O_3 were all larger than PM_{10} [16, 33]. These results suggested that we should not only focus on the PM-related health burden, but also pay attention to the health burden of gaseous pollutants in China.

Existing studies have shown no evidence on a definite threshold concentration in the exposure-response relationships between health effects and air pollutants. For instance, studies conducted in China [23, 34, 35] and North America [36–39] found that an threshold did not existed in the acute effect of short-term O_3 exposure. In addition, the threshold concentrations of PM_{10} , SO_2 , and NO_2 for acute health effects are also not determined [21, 40–42]. Therefore, we set the threshold concentration for each air pollutant to be zero.

This study has several limitations. First, we assumed that the exposure-response coefficients were the same among different cities without taking their spatial variations into account, however, it may differ due to the different age structure [43]; in addition, PM_{10} in different cities may have different chemical compositions, sizes of distribution and sources, which would also trigger different health effects [44–46]. Second, for the exposure-response coefficients obtained from existing studies, which did not consider the synergistic effect of multiple air pollutants, we separately estimated the health burden of a certain air pollutant. Underestimation would exist because populations were usually exposed to multiple environmental risk factors possibly causing synergistic effects [47, 48]. Third, due to inaccessibility to city-specific baseline incidence rates of hospitalization for respiratory and circulatory disease, we assumed these rates being the same among all cities in our study, while substantial disparities may exist due to the differentiations in social economics, social environments and health services.

5. Conclusions

To the best of our knowledge, this is the first work in China to evaluate the health burden and economic loss attributable to short-term exposure to ambient air pollutants at national level. Substantial health burden and economic loss attributable to short-term air pollution exposure were ascertained in our study. The health burden and economic loss associated with gaseous pollutants were significantly higher than

that with particulate matter. We also found some provinces not included in the air pollution priority control areas were also urgently needed to adopt a series of strict air pollution control measures to reduce the health burden. This study has contributed to the limited research concerning the health burden assessment of short-term air pollution exposure.

Abbreviations

PM_{2.5}: particles $\leq 2.5\mu\text{m}$ in aerodynamic diameter, PM₁₀: particles $\leq 10\mu\text{m}$ in aerodynamic diameter, SO₂: sulfur dioxide, NO₂: nitrogen oxide, CO: carbon monoxide, O₃: ozone, VSL: the value of statistical life, COI: cost of illness, GDP: gross domestic product, CPI: consumer price index, HA: hospital admission.

Declarations

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding authors on reasonable request.

Competing interests

The authors declare they have no competing financial interests.

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References

1. Giannadaki D, Giannakis E, Pozzer A, Lelieveld J: *Estimating health and economic benefits of reductions in air pollution from agriculture. Science of the Total Environment* 2018, 622–623(1st May

2018):1304.

- 2.Zhang X, Ou X, Yang X, Qi T, Nam K-M, Zhang D, Zhang X: *Socioeconomic burden of air pollution in China: Province-level analysis based on energy economic model. Energy Economics* 2017, 68:478–489.
- 3.Maji KJ, Ye W-F, Arora M, Nagendra SS: *PM_{2.5}-related health and economic loss assessment for 338 Chinese cities. Environment international* 2018, 121:392–403.
- 4.Hu J, Huang L, Chen M, Liao H, Zhang H, Wang S, Zhang Q, Ying Q: *Premature mortality attributable to particulate matter in China: source contributions and responses to reductions. Environmental science & technology* 2017, 51(17):9950–9959.
- 5.Li T, Guo Y, Liu Y, Wang J, Wang Q, Sun Z, He MZ, Shi X: *Estimating mortality burden attributable to short-term PM_{2.5} exposure: A national observational study in China. Environment international* 2019, 125:245–251.
- 6.Chen H, Yun L, Su Q, Cheng L: *Spatial variation of multiple air pollutants and their potential contributions to all-cause, respiratory, and cardiovascular mortality across China in 2015–2016. Atmospheric Environment* 2017:23–25.
- 7.Lu X, Yao T, Fung JCH, Lin C: *Estimation of health and economic costs of air pollution over the Pearl River Delta region in China. Science of the Total Environment* 2016, 566–567:134–143.
- 8.Hanna R, Oliva P: *The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. Journal of Public Economics* 2015, 122:68–79.
- 9.NHCPRC: *China Health and Family Planning Statistics Yearbook 2018*: National Health Commission of the People's Republic of China; 2017.
- 10.Knowlton K, Rosenthal JE, Hogrefe C, Lynn B, Gaffin S, Goldberg R, Rosenzweig C, Civerolo K, Ku J-Y, Kinney PL: *Assessing ozone-related health impacts under a changing climate. Environmental health perspectives* 2004, 112(15):1557–1563.
- 11.Madaniyazi L, Nagashima T, Guo Y, Yu W, Tong S: *Projecting fine particulate matter-related mortality in East China. Environmental science & technology* 2015, 49(18):11141–11150.
- 12.Madaniyazi L, Nagashima T, Guo Y, Pan X, Tong S: *Projecting ozone-related mortality in East China. Environment international* 2016, 92:165–172.
- 13.Hubbell B, Fann N, Levy JI: *Methodological considerations in developing local-scale health impact assessments: balancing national, regional, and local data. Air Quality Atmosphere & Health* 2009, 2(2):99–110.

- 14.Lai H-K, Tsang H, Wong C-M: *Meta-analysis of adverse health effects due to air pollution in Chinese populations. BMC Public Health* 2013, *13*(1):360.
- 15.Ma H-q, Cui L-h: *Meta-analysis on health effects of air pollutants (SO₂ and NO₂) in the Chinese population. Occupation and Health* 2016, *32*(8):1038–1044.
- 16.Shang Y, Sun Z, Cao J, Wang X, Zhong L, Bi X, Li H, Liu W, Zhu T, Huang W: *Systematic review of Chinese studies of short-term exposure to air pollution and daily mortality. Environment International* 2013, *54*(4):100–111.
- 17.Dong J, Liu x, Zhang B, Wang j, Shang K: *Meta-analysis of association between short-term ozone exposure and population mortality in China. Acta Scientiae Circumstantiate* 2016, *36*(4):1477–1485.
- 18.Yang Y, Cao Y, Li W, Li R, Wang M, Wu Z, Xu Q: *Multi-site time series analysis of acute effects of multiple air pollutants on respiratory mortality: a population-based study in Beijing, China. Science of the Total Environment* 2015, *508*:178–187.
- 19.F L, D X, Y C, S D, C G, X J, X Z: *Systematic review and meta-analysis of the adverse health effects of ambient PM_{2.5} and PM₁₀ pollution in the Chinese population. Environmental research* 2015, *136*(undefined):196–204.
- 20.Wong TW, Lau TS, Yu TS, Neller A, Wong SL, Tam W, Pang SW: *Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. Occupational and environmental medicine* 1999, *56*(10):679–683.
- 21.WHO: *Air quality guidelines: Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Indian Journal of Medical Research* 2007, *4*(4):492–493.
- 22.Burnett RT, Pope III CA, Ezzati M, Olives C, Lim SS, Mehta S, Shin HH, Singh G, Hubbell B, Brauer M: *An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environmental health perspectives* 2014, *122*(4):397–403.
- 23.Chen K, Zhou L, Chen X, Bi J, Kinney PL: *Acute effect of ozone exposure on daily mortality in seven cities of Jiangsu Province, China: No clear evidence for threshold. Environmental Research* 2017, *155*:235–241.
- 24.Xie X: *The Value of Health: Applications of Choice Experiment Approach and Urban Air Pollution Control Strategy*. Peking University; 2011.
- 25.OECD: *The cost of air pollution: Health impacts of road transport: OECD*; 2014.
- 26.Chen X, Wang X, Huang J, Zhang L-w, Song F-j, Mao H-j, Chen K-x, Chen J, Liu Y-m, Jiang G-h: *Nonmalignant respiratory mortality and long-term exposure to PM₁₀ and SO₂: A 12-year cohort study in northern China. Environ Pollut* 2017, *231*:761–767.

- 27.Zhou M, Liu Y, Wang L, Kuang X, Xu X, Kan H: *Particulate air pollution and mortality in a cohort of Chinese men. Environmental Pollution* 2014, 186:1–6.
- 28.Cao J, Yang C, Li J, Chen R, Chen B, Gu D, Kan H: *Association between long-term exposure to outdoor air pollution and mortality in China: a cohort study. Journal of hazardous materials* 2011, 186(2–3):1594–1600.
- 29.Chen Z, Wang J-N, Ma G-X, Zhang Y-S: *China tackles the health effects of air pollution. The Lancet* 2013, 382(9909):1959–1960.
- 30.Yang S, Fang D, Chen B: *Human health impact and economic effect for PM_{2.5} exposure in typical cities. Applied Energy* 2019, 249:316–325.
- 31.Wang Y, Qi Y, Hu J, Zhang H: *Spatial and temporal variations of six criteria air pollutants in 31 provincial capital cities in China during 2013–2014. Environment International* 2014, 73(1):413–422.
- 32.Liu J, Han Y, Tang X, Zhu J, Zhu T: *Estimating adult mortality attributable to PM_{2.5} exposure in China with assimilated PM_{2.5} concentrations based on a ground monitoring network. Science of the Total Environment* 2016, 568:1253–1262.
- 33.Ma HQ, Cui LH: *Meta-analysis on health effects of air pollutants (SO₂ and NO₂) in the Chinese population. Occupation and Health* 2016, 32(8):1038–1044.
- 34.Yang C, Yang H, Guo S, Wang Z, Xu X, Duan X, Kan H: *Alternative ozone metrics and daily mortality in Suzhou: the China Air Pollution and Health Effects Study (CAPES). Science of the Total Environment* 2012, 426:83–89.
- 35.Wong C-M, Vichit-Vadakan N, Kan H, Qian Z: *Public Health and Air Pollution in Asia (PAPA): a multicity study of short-term effects of air pollution on mortality. Environmental health perspectives* 2008, 116(9):1195–1202.
- 36.Bell ML, Peng RD, Dominici F: *The exposure–response curve for ozone and risk of mortality and the adequacy of current ozone regulations. Environmental health perspectives* 2006, 114(4):532–536.
- 37.Smith RL, Xu B, Switzer P: *Reassessing the relationship between ozone and short-term mortality in US urban communities. Inhalation toxicology* 2009, 21(sup2):37–61.
- 38.Katsouyanni K, Samet JM, Anderson HR, Atkinson R, Le TA, Medina S, Samoli E, Touloumi G, Burnett RT, Krewski D: *Air pollution and health: a European and North American approach (APHENA). Research Report* 2009, 142(142):5–90.
- 39.Peng RD, Samoli E, Pham L, Dominici F, Touloumi G, Ramsay T, Burnett RT, Krewski D, Le Tertre A, Cohen A: *Acute effects of ambient ozone on mortality in Europe and North America: results from the APHENA study. Air Quality, Atmosphere & Health* 2013, 6(2):445–453.

40.JY J, PJ V, D P, BH R: *A retrospective cohort study of stroke onset: implications for characterizing short term effects from ambient air pollution. Environmental health: a global access science source* 2011, 10(undefined):87.

41.Laurent F, Alain LT, Isabelle B, Jean-Fran?ois T: *Difference in the relation between daily mortality and air pollution among elderly and all-ages populations in southwestern France. Environmental Research* 2004, 94(3):249–253.

42.Daniels MJ, Dominici F, Zeger SL, Samet JM: *The National Morbidity, Mortality, and Air Pollution Study. Part III: PM10 concentration-response curves and thresholds for the 20 largest US cities. Research report (Health Effects Institute)* 2004(94 Pt 3):1–21; discussion 23–30.

43.Zhang Y, Peng M, Yu C, Zhang L: *Burden of mortality and years of life lost due to ambient PM10 pollution in Wuhan, China. Environmental Pollution* 2017, 230:1073–1080.

44.Pope III CA, Cohen AJ, Burnett RT: *Cardiovascular Disease and Fine Particulate Matter: Lessons and Limitations of an Integrated Exposure–Response Approach. Circulation research* 2018, 122(12):1645–1647.

45.Ostro B, Hu J, Goldberg D, Reynolds P, Hertz A, Bernstein L, Kleeman MJ: *Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California Teachers Study Cohort. Environmental health perspectives* 2015, 123(6):549–556.

46.Laden F, Neas LM, Dockery DW, Schwartz J: *Association of fine particulate matter from different sources with daily mortality in six US cities. Environmental health perspectives* 2000, 108(10):941–947.

47.Kioumourtoglou MA, Schwartz J, James P, Dominici F, Zanobetti A: *PM2.5 and Mortality in 207 US Cities: Modification by Temperature and City Characteristics. Epidemiology* 2016, 27(2):221–227.

48.Konishi S, Ng CFS, Stickley A, Nishihata S, Shinsugi C, Ueda K, Takami A, Watanabe C: *Particulate matter modifies the association between airborne pollen and daily medical consultations for pollinosis in Tokyo. Science of the Total Environment* 2014, 499:125–132.

Tables

Table 1 Percent increase in cause-specific health endpoints along with their 95% confidence intervals for each pollutant

Health endpoints	Air pollutants	Excessive risks	Source
All-cause mortality	PM ₁₀ (10 ug/m ³)	0.31 (0.22 - 0.41)	[14]
	SO ₂ (10 ug/m ³)	0.90 (0.60 - 1.10)	[21]
	NO ₂ (10 ug/m ³)	1.40 (1.10 - 1.60)	[21]
	CO (1 mg/m ³)	3.70 (2.88 - 4.51)	[16]
	O ₃ (10 ug/m ³)	0.40 (0.30 - 0.50)	[22]
Cardiovascular mortality	PM ₁₀ (10 ug/m ³)	0.49 (0.34 - 0.63)	[14]
	SO ₂ (10 ug/m ³)	0.70 (0.50 - 0.80)	[21]
	NO ₂ (10 ug/m ³)	1.40 (1.10 - 1.50)	[21]
	CO (1 mg/m ³)	4.77 (3.53 - 6.00)	[16]
	O ₃ (10 ug/m ³)	0.45 (0.17 - 0.72)	[22]
Respiratory mortality	PM ₁₀ (10 ug/m ³)	0.57 (0.40 - 0.75)	[14]
	SO ₂ (10 ug/m ³)	1.20 (0.90 - 1.60)	[21]
	NO ₂ (10 ug/m ³)	1.60 (1.20 - 1.90)	[21]
	CO (1 mg/m ³)	2.99 (0.85 - 5.11)	[18]
	O ₃ (10 ug/m ³)	0.46 (0.23 - 0.70)	[22]
Cardiovascular hospital admissions	PM ₁₀ (10 ug/m ³)	0.37 (0.17 - 0.56)	[19]
	SO ₂ (10 ug/m ³)	0.90 (0.50 - 1.40)	[21]
	NO ₂ (10 ug/m ³)	1.30 (0.90 - 1.60)	[21]
	O ₃ (10 ug/m ³)	1.30 (0.50 - 2.10)	[20]
Respiratory hospital admissions	PM ₁₀ (10 ug/m ³)	0.51 (0.23 - 0.79)	[19]
	SO ₂ (10 ug/m ³)	2.54 (1.51 - 3.59)	[21]
	NO ₂ (10 ug/m ³)	2.36 (1.75 - 2.98)	[21]
	O ₃ (10 ug/m ³)	2.20 (1.50 - 2.90)	[20]

Figures

Figure 1

Spatial distribution of population and average annual air pollutants concentrations in 338 cities in China in 2017: (a) Population, (b) PM₁₀, (c) SO₂, (d) NO₂, (e) CO, and (f) O₃. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Spatial distribution of the premature deaths in all-cause mortality in 338 cities in China in 2017: (a) all air pollutants, (b) PM₁₀, (c) SO₂, (d) NO₂, (e) CO, and (f) O₃. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

The contributions of air pollutants in all-cause mortality in 338 cities in China in 2017: (a) all air pollutants, (b) PM₁₀, (c) SO₂, (d) NO₂, (e) CO, and (f) O₃. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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