Population weighted distribution of PM$_{2.5}$ in 31 provinces in China

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Abstract. The traditional calculated PM$_{2.5}$ based on the simple arithmetic average method (SAAM) is not adequate enough to reflect the influence of air pollution to public health and the exposed public. Considering the exposed population to air pollution, this study calculated PPM$_{2.5}$ in 31 provinces in China by using the population weighted arithmetic average method (PWAA). The study shows that in 2018, most provinces have a significant difference between the populations weighted PM$_{2.5}$ (PPM$_{2.5}$) and the simple average value (PM$_{2.5}$) in which Qinghai and Sichuan have the highest differences. Moreover, from 2013 to 2018, PPM$_{2.5}$ based on 346 cities is higher than PM$_{2.5}$ and the differences grow in escalation. Thus, compared with the SAAM, PPM$_{2.5}$ based on the PWAA can reflect explicitly the impact of air pollution to the exposed population.

1. Introduction

China is in the process of rapid industrialization and urbanization, and the risk of PM$_{2.5}$ exposure is very serious in urban areas with intensive human activities. In 2005, WHO promulgated the air quality standards for the healthy concentration of PM$_{2.5}$ in 24h is 25μg/m$^3$\cite{1}, and the secondary limit of PM$_{2.5}$ concentration in China's ambient air quality standards is 75μg/m$^3$, which is three times higher than the WHO standard\cite{2}. At present, the concentration of PM$_{2.5}$ in most Chinese cities far exceeds the WHO standard\cite{3}. Therefore, quantitative PM$_{2.5}$ assessment has become an important prerequisite for population health risk assessment.

At present, the average PM$_{2.5}$ concentration of all provinces in China is calculated by using the arithmetic average of the annual average monitored by all prefecture-level cities in the province. While simple and straightforward, this calculation has its drawbacks, especially since it does not take into account the impact of air pollution on exposed populations. In general, the same concentration of PM$_{2.5}$ is more harmful to public health in densely populated areas than in less densely populated ones. This risk to public health cannot be reflected by the current arithmetical mean method, so population-weighted analysis is required.

2. Methods and data

2.1. Methods of the population-weighted exposure level

The spatial distribution of population size is not completely consistent with the distribution of pollutant concentration, and the spatial distribution of PM$_{2.5}$ concentration cannot reflect the real exposure risk of residents. Population-based exposure risk assessment can more reasonably reflect the
exposure risk of PM$_{2.5}$ in the study area. The formula for population-weighted exposure level (PWEL) is as follows$[4]$:

$$\text{PWEL} = \frac{\sum (p_i \times C_i)}{\sum p_i},$$

where $i$ is the grid number; $p_i$ is the number of population in the grid; $C_i$ is the atmospheric pollutant concentration within the grid (μg/m$^3$).

2.2. Data

The data used in this study mainly include PM$_{2.5}$ and urban exposed population.

PM$_{2.5}$: The data are from the National Urban Air Quality Real-time Release Platform of China's Environmental monitoring headquarters and data released by the Ministry of Environmental Protection.

Urban exposed population: The national urban exposed population data is from China Urban Statistical Yearbook$[5]$, and the data used is the average annual population in that year. Due to the time limitation of demographic data statistics, the population from 2013 to 2018 is uniformly calculated by the population from 2012 to the end of 2017.

3. Results and Discussion

3.1. The distribution of PM$_{2.5}$ and PPM$_{2.5}$ at provincial level in 2018

Based on the above methods and data calculation, PPM$_{2.5}$ of 31 provinces and municipalities in 2018 is obtained, as shown in Fig. 1. As can be seen from Fig. 1, except Shanghai and Jiangsu, PPM$_{2.5}$ and PM$_{2.5}$ in most other provinces have significant differences, among which Qinghai and Sichuan have the largest difference. What Qinghai and Sichuan have in common is that Xining and Chengdu, the provincial capital, have a higher PM$_{2.5}$ density than others, and its urban population accounts for a large proportion of the province's population. In this case, the population-weighted mean increased the PPM$_{2.5}$ of the province.
3.2. Annual variation of PM$_{2.5}$ and PPM$_{2.5}$ nationwide

Calculations show that from 2013 to 2018, PPM$_{2.5}$ nationwide based on 346 cities is higher than PM$_{2.5}$, and the difference between the two is significant. This suggests that although PM$_{2.5}$ monitoring has been falling slightly, urban populations are gathering in cities with high air pollution concentrations. The results also showed a 20.7% decrease in the concentration of PM$_{2.5}$ (23μg/m$^3$) in 2016, compared with 29μg/m$^3$ in 2013. Compared to PPM$_{2.5}$ (57μg/m$^3$) in 2013, PPM$_{2.5}$ (46μg/m$^3$) in 2016 was only...
15.8% lower. Therefore, when population exposure is taken into account, the improvement of PPM$_{2.5}$ is significantly smaller than that of PM$_{2.5}$. (Fig. 2)

![Figure 2. Comparison of the annual mean value of PPM$_{2.5}$ and PM$_{2.5}$ in China from 2013 to 2018.](image)

4. Conclusions

This study shows that there is a significant difference between the annual mean value of PPM$_{2.5}$ calculated by weighted urban exposed population and the annual mean value of PM$_{2.5}$ calculated by arithmetic mean method. First of all, in 2018, PPM$_{2.5}$ and PM$_{2.5}$ concentrations in various provinces are different from each other, and the difference is closely related to urban population exposure and pollution. Second, the difference between the two PM$_{2.5}$ algorithms is significant, indicating that more people are gathering in areas with higher air pollution. While the pollutant concentration index has decreased, its effect on the exposed population has not decreased. This problem deserves further consideration and analysis. Therefore, this paper suggests that in practical work, in order to more reasonably reflect the relationship between air pollution level and exposed population, PPM$_{2.5}$ with population weighting method can be considered as a supplementary index of PM$_{2.5}$.

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