Preplanned Studies

# Baseline Investigation on Residential $PM_{2.5}$ Pollution of General Living Scenarios — 12 Cities, China, 2018

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**Summary**

**What is already known about this topic?**

Residential air pollution can cause a large disease burden, and residential air quality is directly influenced by residential fine particulate matter ($PM_{2.5}$). Residential $PM_{2.5}$ pollution is of critical concern in China given that the characteristics and influencing factors of residential $PM_{2.5}$ in China are not clear.

**What is added by this report?**

This study focuseed on residential $PM_{2.5}$ concentration of 12 cities with the on-site investigation in 2018, and provided the latest characteristics and potential influencing factors of residential $PM_{2.5}$ under general living scenarios in China.

**What are the implications for public health practice?**

This study suggested that the control of residential $PM_{2.5}$ pollution should be reinforced with revised indoor air quality standards under obvious spatial diversity.

Short-term and long-term exposure to outdoor airborne fine particulate matter (particles with aerodynamic diameter ≤2.5 μm; $PM_{2.5}$) can increase the morbidity and mortality of cardiovascular and respiratory diseases (*1*). Considering time-activity patterns, people spent 85%–90% of their daily time in households (*2*), and for indoor $PM_{2.5}$ pollution, some studies were reported from many countries with a focus on special conditions such as residential ventilation, biofuel combustion, environmental tobacco smoke, etc (*3*–*4*). With rapid urbanization, residential $PM_{2.5}$ pollution still remains to be studied in many cities of China, especially under daily general living circumstances.

To explore the representative levels, characteristics, and influencing factors of residential $PM_{2.5}$ pollution in China, the National Institute of Environmental Health (NIEH) of China CDC initiated a multicenter investigation for indoor air pollution in 2018. The study selected cities and resident families based on two-step random sampling. Twelve representative cities were selected considering various factors such as climatic and geographical locations. These cities were mainly from the Northeast (Harbin and Panjin), Northwest (Lanzhou and Xi'an), Southwest (Mianyang), North (Shijiazhuang), East (Wuxi, Ningbo and Qingdao), Central (Luoyang), and South (Nanning and Shenzhen) of China. The selected cities within the zone of temperate climate were Harbin, Panjin, Qingdao, Shijiazhuang, Lanzhou, Luoyang, and Xi'an, and the selected cities within the zone of subtropical climate included the other five cities. The sampling dates were in the cold season (December) and the warm season (June) in 2018. Samples from families of Xi'an and Mianyang were collected only in the cold season because of unexpected interruptions to the field investigation.

Resident families in each city were randomly selected from one district downwind of the city center and another district located upwind. At least 25 families in each district were identified as confirmed target households with the following inclusion criteria: 1) families lived in the house for more than 3 years without plans to move away in the next 3 years; 2) families included at least one infant; and 3) families were willing to participate in this investigation. Families including individuals engaged in occupations with high health risks caused by environmental pollution and with any individuals smoking regularly were excluded.

In order to collect representative data of residential air quality, samples from bedrooms and living rooms of each family were collected by local CDCs. To collect the data of residential pollution with many parameters such as $PM_{2.5}$ related to the unified general living scenario of each household, the sampling condition of each family was regulated with the following guidelines: 1) the doors and windows were pre-closed for 12 hours for indoor sampling; 2) air conditioners, fans, and other equipment that may interfere with airflow were all turned off during the sampling period; 3) the period between 9 AM to 10 AM was chosen as the preferred sampling time to avoid traffic peaks and indoor cooking; 4) behaviors like indoor smoking were prohibited and temporary visiting guests were avoided for sampling in all families under the general living circumstances; 5) the height of the measuring point was 1 to 1.5 meters above the ground; and 6) the measuring point was not less than 0.5 meters from the wall. Indoor air quality indicators in this study included temperature, humidity, $PM_{2.5}$, $PM_{10}$ (particles with aerodynamic diameter ≤10 μm; $PM_{10}$), etc. $PM_{2.5}$ and $PM_{10}$ were monitored by calibrated light-scattering dust meters. The average value of 10 monitoring values recorded on a 5 minute interval was consistently taken as the final representative concentration for a site in living rooms and bedrooms. Approximately 3% of the total rooms were monitored repetitively as the parallel sites, and the sampling method had acceptable repeatability. The family members were interviewed about the lifestyles and living conditions of households with questionnaires. Informed consent forms were signed before the investigation. The sample size of target families was calculated based on a cross-sectional study design. Finally, after accounting for data censoring and the lack of coordination of the families, a total of 642 families were identified to evaluate residential air pollution in 12 major cities in China.

In 2018, the population in all selected cities was exposed to a residential $PM_{2.5}$ average concentration of 79.34 μg/m$^3$, and the $PM_{2.5}$ concentration distribution in each city was also shown (Table 1). A significant difference was found in $PM_{2.5}$ concentrations among 12 cities ($F=72.13$, $p<0.001$). The concentration of residential $PM_{2.5}$ in two seasons was significantly different in 7 representative cities including Harbin, Panjin, Qingdao, Shijiazhuang, Lanzhou, Luoyang, and Wuxi ($p<0.05$) (Figure 1).

Residential $PM_{2.5}$ concentration in this study was not normally distributed, so we estimated the odds ratio and corresponding 95% confidence interval (95% CI) for each potential risk factor by using the generalized linear model (GLM) with Poisson connection function (Table 2). After adjusting for the influence of $PM_{10}$, the concentrations of residential $PM_{2.5}$ in warm climate zones were found to be likely higher than those in the cold climate zone ($OR_2$=1.4454, 95% CI: 1.3973–1.4951). Statistically significant associations were found with residential $PM_{2.5}$ and physical indicators including temperature ($OR_2$=0.9436, 95% CI: 0.9406–0.9465) and humidity ($OR_2$=0.9906, 95% CI: 0.9894–0.9918). For the residential environment, households more than 1 kilometer away from the road had a lower residential $PM_{2.5}$ concentration than those less than 1 kilometer ($OR_2$=0.7511, 95% CI: 0.7103–0.7937).

Architectural characteristics showed potential influences on residential $PM_{2.5}$. As to the layers of window glass, the $PM_{2.5}$ concentrations in families with more than two layers were higher than those of less than two layers ($OR_2$=1.2841, 95% CI: 1.1694–1.4066). In addition, the $PM_{2.5}$ concentrations in households between the 5th and

TABLE 1. Description of residential $PM_{2.5}$ of 12 cities in China, 2018 (μg/m$^3$).

| Cities | Mean | SD | Min | $P_{25}$ | $P_{50}$ | $P_{75}$ | Max |
|---|---|---|---|---|---|---|---|
| Harbin | 38.03 | 26.37 | 0.00 | 21.75 | 31.50 | 47.00 | 193.00 |
| Panjin | 83.10 | 50.33 | 9.00 | 54.25 | 73.45 | 96.48 | 541.00 |
| Qingdao | 49.24 | 48.68 | 9.00 | 20.00 | 35.00 | 54.50 | 272.00 |
| Shijiazhuang | 66.60 | 47.21 | 4.00 | 33.00 | 60.50 | 90.00 | 295.00 |
| Lanzhou | 174.30 | 150.41 | 0.00 | 89.25 | 144.50 | 232.75 | 968.00 |
| Luoyang | 83.65 | 65.72 | 8.00 | 43.25 | 62.00 | 109.00 | 380.00 |
| Xi'an | 101.88 | 102.88 | 14.00 | 46.75 | 76.50 | 120.25 | 690.00 |
| Wuxi | 68.96 | 66.72 | 2.00 | 26.50 | 45.00 | 85.50 | 401.00 |
| Mianyang | 220.38 | 156.67 | 60.00 | 90.00 | 182.50 | 349.50 | 531.00 |
| Ningbo | 33.09 | 21.39 | 5.00 | 16.00 | 27.90 | 50.65 | 102.83 |
| Nanning | 59.60 | 13.36 | 24.00 | 54.50 | 65.00 | 70.00 | 74.00 |
| Shenzhen | 43.82 | 23.51 | 11.00 | 29.25 | 41.00 | 49.00 | 137.00 |

Note: To correct the extreme value of $PM_{2.5}$ in Lanzhou, we used the 95% quantile of the same city in the same season to take place of it.
Abbreviations: SD=standard deviation, Min=minimum, $P_{25}$=25th perquartile, $P_{50}$=median, $P_{75}$=75th percentile, Max=maximum.

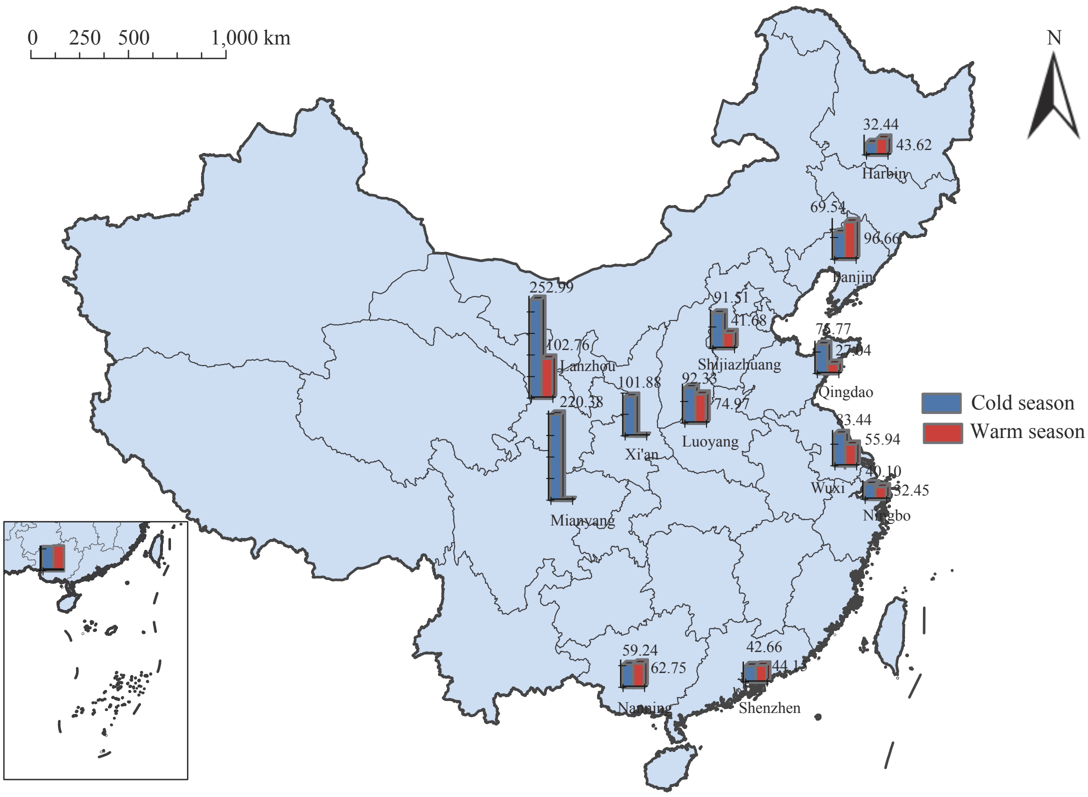


FIGURE 1. Spatial and seasonal distribution of residential $PM_{2.5}$ of 12 cities in China, 2018 ($\mu g/m^3$).

10th floors ($OR_2$=1.1102, 95% CI: 1.0788–1.1425) and above 10th floor ($OR_2$=1.1616, 95% CI: 1.1276–1.1965) were higher than those in households below the 5th floor. Compared with bungalows, the residential $PM_{2.5}$ concentrations were higher in buildings ($OR_2$=1.3860, 95% CI: 1.3028–1.4760).

Some family-related information and lifestyle habits may also influence residential $PM_{2.5}$. As for the influence of family economic status, compared with families with an annual total income of fewer than 100,000 RMB (roughly 14,300 USD), households with an annual income of 100,000 to 200,000 RMB ($OR_2$=0.8209, 95% CI: 0.8004–0.8419) and an income of more than 200,000 RMB ($OR_2$=0.8074, 95% CI: 0.7778–0.8379) had lower residential $PM_{2.5}$ concentrations. The study also found that the average living area of family members showed a positive correlation with residential $PM_{2.5}$ concentration ($OR_2$=1.0020, 95% CI: 1.0008–1.0032). As for lifestyle habits, the $PM_{2.5}$ concentrations of households that never use air purifiers were significantly higher than those families using air purifiers ($OR_2$=1.0856, 95% CI: 1.0551–1.1170). The frequency of using the range hood in the kitchen was also correlated with residential $PM_{2.5}$. The $PM_{2.5}$ concentrations in households using range hoods frequently ($OR_2$=0.8864, 95% CI: 0.8207–0.9588) and occasionally ($OR_2$=0.5241, 95% CI: 0.4366–0.6253) were lower than those that never used the range hoods. Moreover, households without carpets showed lower $PM_{2.5}$ concentrations than those with carpets ($OR_2$=0.8027, 95% CI: 0.7699–0.8372), and households that never grow plants had a higher $PM_{2.5}$ concentration than those grow plants ($OR_2$=1.0284, 95% CI: 1.0020–1.0555).

## DISCUSSION

This study was one of few studies that uses extensive multi-center data obtained through face-to-face surveys in China. Variability in residential $PM_{2.5}$ concentrations in 12 cities was possibly related to a combination of differences in the sources of pollution (road dust, automobile exhaust, and coal combustion sources) (*5*), meteorological factors (wind speed, atmospheric stability), and family living habits. Seasonal variations of $PM_{2.5}$ in 7 representative cities may be caused partially by outdoor temperature and humidity (*3*). Moreover, we found significant correlations between residential $PM_{2.5}$ and physical

TABLE 2. Some potential influencing factors and the concentrations of residential $PM_{2.5}$ of 12 cities in China, 2018.

| Variables | Categories | $OR_1$ (95% CI) | $p_1$ | $OR_2$ (95% CI) | $p_2$ |
|---|---|---|---|---|---|
| $PM_{10}$ (μg/$m^3$) | | | | 1.0055 (1.0054,1.0056) | <0.001 |
| Temperature (℃) | | 0.9286 (0.9258, 0.9315) | <0.001 | 0.9436 (0.9406, 0.9465) | <0.001 |
| Humidity (%) | | 0.9938 (0.9926, 0.9949) | <0.001 | 0.9906 (0.9894, 0.9918) | <0.001 |
| Climate zones (*vs.* Cold) | Warm | 0.9840 (0.9535, 1.0154) | 0.315 | 1.4454 (1.3973, 1.4951) | <0.001 |
| Distance from road (*vs.* <1 km) | >1 km | 0.7739 (0.7328, 0.8167) | <0.001 | 0.7511 (0.7103, 0.7937) | <0.001 |
| Window glass types (*vs.* ≤2 layers) | >2 layers | 0.8546 (0.7792, 0.9349) | <0.001 | 1.2841 (1.1694, 1.4066) | <0.001 |
| Living floor (*vs.* ≤5) | 5–10 | 1.1160 (1.0846, 1.1481) | <0.001 | 1.1102 (1.0788, 1.1425) | <0.001 |
| | ≥10 | 1.1742 (1.1398, 1.2094) | <0.001 | 1.1616 (1.1276, 1.1965) | <0.001 |
| Construction house types (*vs.* Bungalow) | Building | 1.1953 (1.1245, 1.2719) | <0.001 | 1.3860 (1.3028, 1.4760) | <0.001 |
| | Villa | 0.6682 (0.5787, 0.7685) | <0.001 | 0.8942 (0.7737, 1.0292) | 0.124 |
| Renovate in the past 5 years (*vs.* Yes) | No | 1.0519 (1.0259, 1.0787) | <0.001 | 0.9912 (0.9663, 1.0168) | 0.496 |
| Income (yearly) (*vs.* <100,000 RMB) | 100,000–200,000 RMB | 0.9030 (0.8803, 0.9263) | <0.001 | 0.8209 (0.8004, 0.8419) | <0.001 |
| | ≥200,000 RMB | 0.7842 (0.7555, 0.8139) | <0.001 | 0.8074 (0.7778, 0.8379) | <0.001 |
| Average living area ($m^2$) | | 0.9949 (0.9938, 0.9961) | <0.001 | 1.0020 (1.0008, 1.0032) | 0.001 |
| House cleaning (*vs.* More than once a month) | Less than once a month | 2.8896 (2.5724, 3.2339) | <0.001 | 0.9506 (0.8447, 1.0660) | 0.393 |
| Grow plants (*vs.* Yes) | No | 1.1078 (1.0798, 1.1364) | <0.001 | 1.0284 (1.0020, 1.0555) | 0.034 |
| Carpet (*vs.* Yes) | No | 0.7953 (0.7630, 0.8294) | <0.001 | 0.8027 (0.7699, 0.8372) | <0.001 |
| Burn incense (*vs.* Yes) | No | 1.0935 (1.0538, 1.1350) | <0.001 | 0.9965 (0.9599, 1.0347) | 0.853 |
| Air purifier (*vs.* Yes) | No | 1.0480 (1.0188, 1.0781) | 0.001 | 1.0856 (1.0551, 1.1170) | <0.001 |
| Range hook (*vs.* Never) | Occasionally | 0.6214 (0.5178, 0.7411) | <0.001 | 0.5241 (0.4366, 0.6253) | <0.001 |
| | Frequently | 1.0849 (1.0048, 1.1731) | 0.039 | 0.8864 (0.8207, 0.9588) | 0.002 |

Note: The variables after *vs.* represent the reference variables in statistical analysis. The value of $OR_1$ indicates that while keeping other predictor variables unchanged, the logarithm of residential $PM_{2.5}$ concentration was $OR_1$ times of the individual reference variable. The value of $OR_2$ indicates that when $PM_{10}$ was introduced into the model to adjust its impact on $PM_{2.5}$, while keeping other predictors unchanged, the logarithm of residential $PM_{2.5}$ concentration was $OR_2$ times of the individual reference variable.
Abbreviations: CI=confidence interval.

environmental indicators such as temperature and humidity.

Outdoor $PM_{2.5}$ was also a major contributor to residential particle concentrations (*6*), and the residential $PM_{2.5}$ concentration showed an upward trend with an increase in altitude. This may be related to the vertical diffusion capacity of the atmosphere and the characteristics of the particulate matter, especially changes in wind speed at varying vertical heights (*7*). Household economic levels and average per capita area may also affect $PM_{2.5}$ concentrations to some extent, which may be caused by lifestyle behaviors of family members (*8*). Some lifestyle habits were associated with the concentration of residential $PM_{2.5}$. Housekeeping activities, such as sweeping and vacuuming, were associated with increased concentrations of residential $PM_{2.5}$ because household cleaning could possibly disturb deposited particles from domestic floors and furniture (*8*). The use of air purifiers and range hoods might also reduce residential $PM_{2.5}$ concentration to a certain extent (*9*).

This study was subject to several limitations. First, in cross-sectional studies, selection bias and information bias could be a problem even though households were selected randomly in each city. Secondly, some potential influencing factors of residential $PM_{2.5}$ might be missed in this investigation due to the limited two times of sampling.

The findings highlighted the importance of an improvement plan for residential air quality. Public health supervision of residential $PM_{2.5}$ pollution should be pushed forward according to the distribution pattern of $PM_{2.5}$ in different cities. Additional information and incentives to eliminate residential $PM_{2.5}$ pollution are needed urgently to guide healthier behavior in families.

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