The impact of $PM_{2.5}$ pollution on residents' health and economic loss accounting in China

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Abstract:

Reasonable assessment of the health risks and economic losses of urban residents caused by air pollution is of great significance for regional air pollution control, environmental policy planning and implementation, and the construction of health in China. Based on the data of $PM_{2.5}$ Concentration and population density in 338 Cities of China from 2015 To 2017, this paper estimates the premature death and related disease incidence caused by exposure to $PM_{2.5}$ Pollution by the means of the Exposure-Response model,and assesses the direct economic losses of $PM_{2.5}$ Pollution by the methods of the Life Value Method (VSL) and Disease Cost (COI). The results show that: 1) From 2015 To 2017, $pM_{2.5}$ Mass concentration has improved to some extent, but the overall spatial pollution pattern has not changed significantly. The highly polluted areas are mainly distributed in the Beijing-Tianjin-Hebei regions and their surrounding cities; 2) $PM_{2.5}$ Pollution has led to a significant reduction in terminal health losses and economic losses. Among them, the number of residents who lost terminal health decreased by 23.9%,the total economic loss of residents decreased by 24.24% from 1 824.96 Billion yuan in 2015 To 1 382.64 Billion yuan in 20173) The increase of urbanization rate exacerbates the impact of $PM_{2.5}$ Pollution on the health problems and corresponding economic losses, especially in some cities with high pollution and high urbanization level, such as Beijing and Tianjin. In the future, measures should be taken in line with local conditions to strengthen $PM_{2.5}$ Monitoring and control in key cities and effectively protect the public health of urban residents.

Keywords: $PM_{2.5}$ Concentration; Urbanization; Residents' health; Exposure-response function; Economic loss; Air pollution control; Healthy China

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With the rapid development of China's industrialization, the assessment of residents' health loss and social and economic benefit loss caused by environmental problems and

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※ corresponding author: chenkunlun (1982 -), male, born in Jingmen, Hubei Province, doctor, Professor, doctoral supervisor, research direction: urban geography. E-mail:ckl_ 2001@163.com environmental pollution has gradually become a hot spot, such as the residents' health impact caused by urban air pollution [1-2]. Existing environmental epidemiological studies have shown that short-term or long-term exposure to heavily polluted air environment will damage the human respiratory, cardiovascular and immune systems, cause mutations in DNA, chromosomes and other structures, and have a significant impact on premature death and birth defects of newborns [3-6]. However, in the context of rapid urbanization, the number of people exposed to pollution has increased due to high population density and population mobility [7-8], and high pollution and high exposure have made the health problems of urban residents more prominent. Therefore, a reasonable assessment of the residents' health impact and economic losses caused by urban air pollution is of great significance for air pollution control and the construction of a healthy China.

In recent years, with the deepening and refinement of air pollution research, more and more attention has been paid to the estimation of large sample urban health loss caused by air pollution factors from the perspective of environmental risk and environmental economy. In terms of research content, since experts in the field of public health put forward the concept of global disease burden, many scholars have measured how $PM_{2.5}$ affects mortality, disease incidence, hospitalization rate, working hours, etc. Through experiments, questionnaires, field surveys and other ways when exposed to air pollution [9-11]. The results show that if the annual average concentration of $PM_{2.5}$ is reduced, the life expectancy of the population will increase [12] and the economic benefit will also increase [13]; otherwise, it will bring varying degrees of loss and harm. For example, lihuijuan et al. Evaluated 62 key environmental protection cities in China. The results showed that $PM_{2.5}$ pollution caused about 125000 premature deaths and 570.5 billion yuan of economic losses [14]; xiezhixiang and other researchers showed that in 2015, the number of deaths caused by $PM_{2.5}$ pollution in Beijing Tianjin Hebei air pollution transmission channel was about 307000, accounting for 28.6% of the total number of deaths [15]. However, in the empirical study, due to the differences in the selection of urban sample size, research methods, reference year, reference concentration and air pollution factors, the exposure response coefficients obtained from different epidemic cases will be quite different, which will bring some deviation to the actual health or economic loss estimation results [16-17]. From the perspective of research methods, in order to intuitively understand the adverse impact of air pollution on Residents' health, scholars use the human capital method, the revised human capital method, the value of life (VSL), the willingness to pay (WTP), the marginal willingness to pay (mwtp), the cost of disease (COI) method and the scenario analysis method to assess the impact of air pollution on the economy and calculate the amount of relevant economic losses caused by pollution [18-21]; other scholars use the input-output model of economics or the computable general equilibrium model for reference to estimate the impact of air pollution on the macro economy [22-23]. Different evaluation and accounting methods have their own advantages and disadvantages. With the continuous improvement of public health data statistics and the continuous improvement of data quality, the estimation results of life value method and disease cost method will be closer to reality and more reliable [21]. From the research scale, the empirical studies of different scholars mainly focus on the analysis and comparison at the national level, multiple city levels (large samples) and single city level, but the time section mainly selects the analysis of a single year [21,24].

In general, the existing research provides a useful idea and analysis framework for scientifically exploring the comparison of air pollution health loss and regional (urban) differences. In addition, at present, $pM_{2.5}$ health loss assessment is paying more and more attention to large sample city scale epidemic research cases, but it lacks comparative evolution research at the time level, and pays less attention to the socio-economic impact factors of residents' health loss, such as $PM_{2.5}$ health loss assessment driven by different urbanization levels. In order to improve the research accuracy of $PM_{2.5}$ exposure response coefficient and reflect the difference of health loss at different urbanization levels, exploring the relationship between urbanization and $PM_{2.5}$ health loss (whether it is intensified or mitigated) has become a new focus in the implementation of China's new urbanization and health strategy [24-27]. Based on this, this paper provides a comprehensive health risk assessment based on the $PM_{2.5}$ data of cities in 31 provinces of China in 2015 and 2017 (not including Hainan Sansha City, hong Kong, macao and Taiwan), combined with urbanization and population density data, and then makes an economic assessment on the health impact of $PM_{2.5}$ in China based on relevant medical data, tests the economic losses under different urbanization levels, and explores the relationship between urbanization and health loss, it is helpful to comprehensively understand and grasp the great threat of air pollution on the urban scale. At the same time, the comparison of health risks and economic losses among different urbanization levels and regions can provide cost-benefit analysis basis or decision-making reference for national regional cooperation in air pollution control, the construction of beautiful China and healthy China, so as to reduce the welfare losses of the whole society.

1 Data sources and research methods

1.1 Data source

The data involved in this study are mainly composed of five parts: $PM_{2.5}$ pollution data, population density and urbanization rate data, per capita GDP related economic data, outpatient service or hospitalization expenses and other medical related data.

In order to reduce the possible error and data loss caused by the use of ground monitoring points and improve the accuracy of calculation results, this paper adopts the air pollution data based on satellite remote sensing [28-29]. Generally speaking, the remote sensing image data can reflect the comprehensive contribution of all emission sources compared with the limited monitoring point data on the ground, so it can better measure the average level of urban air pollution [2,30]. Therefore, the $PM_{2.5}$ pollution data in this paper adopts the global annual satellite derived $PM_{2.5}$ product with a resolution of 0.1 ° provided by atmospheric composition analysis group, and then uses zoom statistics to measure the $PM_{2.5}$ pollution status in 2015 and 2017 at the urban scale in China (Figure 1).

At the same time, the year-end resident population [31] is often used in the relevant exposure response calculation of health terminal changes. The population estimated by the census and spot check ignores a large number of floating population, which will bring great deviation to the final results. Therefore, this paper uses satellite remote sensing data to calculate the population size of each city, which can more accurately estimate the actual total population currently exposed to $PM_{2.5}$ pollution [2,32]. Specific population density data are provided by gist (Geographic Information Science and Technology) for 1 km × Calculated from land scan data with a resolution of 1 km. The urbanization rate, per capita GDP and per capita disposable income come from the 2016 and 2018 China Urban Statistical Yearbook and the statistical yearbook of each province. The unit outpatient service or hospitalization expenses come from the 2016 and 2018 China Health and family planning statistical yearbook.

1.2 Research methods

1.2.1 Exposure response function

For the environmental health risk assessment caused by air pollution, the existing research mainly obtains the exposure response relationship between air pollutant concentration and population health effect from epidemiological observation, and then deduces it according to the relative risk model of Poisson regression [33-34]. In this model, the health risk (morbidity or mortality) of the health terminal of the population under the actual concentration of $PM_{2.5}$ pollution is set as:

$$I = I_0 \times \exp\left[\beta \times \left(C - C_0\right)\right] \qquad (1)$$

Therefore, the health risk change of $PM_{2.5}$ pollution can be expressed as:

$$\begin{aligned} E &= P \times \Delta I = P \times \left(I - I_0\right) \\ &= P \times I \times \left\{1 - \frac{1}{\exp\left[\beta \times \left(c - c_0\right)\right]}\right\} \end{aligned} \qquad (2)$$

Where: E refers $PM_{2.5}$ to the change of health terminal caused by P concentration change; is the I exposed $PM_{2.5}$ population; is the health risk of residents I_0 caused by the actual concentration; $PM_{2.5}$ Indicates the health risk C caused by $PM_{2.5}$ the reference C_0 concentration; $PM_{2.5}$ Represents the actual concentration, β and is the reference concentration of; to expose a response function.

Exposure response function analysis comes from a series of research results that reveal the impact of long-term exposure to polluted air on human health, such as the widely adopted Harvard Six Cities Study and the research coefficient of the American Cancer Society [35]. However, these two studies are the research results under the background of low $PM_{2.5}$ concentration in the United States, and the exposure response coefficient obtained from these studies is not applicable to the current actual situation in China. Therefore, this paper refers to the research of huangdesheng, wangguizhi, etc. [20,23], and selects its exposure response coefficient to evaluate the health effects of different health terminals. The specific coefficients are as follows:

According to the air quality guidelines issued by the World Health Organization in 2005 (who, 2006), the annual average exposure concentration is 10 $\mu g/m^3$ is used as the reference value for long-term exposure of $PM_{2.5}$ [36]. This concentration is the lower limit of the concentration range that has a significant impact on survival observed in the study conducted by the American Cancer Society (ACS) [37]. Compared with the grade I standard (15) for the annual limit of $PM_{2.5}$ in China's ambient air quality standard (gb3095-2012) $\mu g/m^3$), secondary standard (35 $\mu g/m^3$), the reference value selected in this study is 10 $\mu g/m^3$ is more stringent, and the resulting health risk value estimation results will become larger and more serious. This will help reassess the health risks and severe challenges caused by $PM_{2.5}$ pollution under a higher standard.

1.2.2 VSL and COI

There are mainly two kinds of direct economic losses caused by the change of $PM_{2.5}$ concentration: one is the economic losses caused by the early death caused by pollution and the loss of labor, which are estimated by the value of life (VSL) [2,38]; the other is the medical expenses caused by the increase of the incidence rate of related diseases caused by $PM_{2.5}$ pollution. The disease cost method (COI) is used to calculate [2,21,39]. The specific estimation formula is as follows:

$$DEL = VSL + \sum_i HE_i \tag{3}$$

$$HE_i = \sum_i E_i \times RP_i \tag{4}$$

Where: refers i to the $PM_{2.5}$ type of disease caused by pollution; means HE_i the additional medical expenses i incurred by the residents due to the category of RP_i diseases; outpatient service or hospitalization expenses of the representative E_i unit; refers $PM_{2.5}$ to the number of i residents suffering from class I disease caused by pollution; vSL represents the economic loss caused by premature $PM_{2.5}$ death; del refers to the direct economic loss caused by pollution [2,38].

2 Result Analysis

2.1 Relationship between $PM_{2.5}$ Pollution distribution and urbanization

2.1.1 Spatial distribution characteristics of $PM_{2.5}$ Concentration

Through the processing of satellite remote sensing data, the spatial distribution map of China's $PM_{2.5}$ concentration in 2015 and 2017 is obtained, as shown in Figure 1. 1 km on the left × The remote sensing map of $PM_{2.5}$ concentration with an accuracy of 1 km. On the right is the annual average $PM_{2.5}$ concentration distribution at the urban level after zonal statistical processing.

Table 1 Exposure-response coefficient and incidence of $PM_{2.5}$ Pollution

Be ill		Exposure response coefficient mean (95% confidence interval)	I value
Premature death	All cause death	0.00296(0.00076, 0.00504)	0.00452
Hospitalization	Respiratory diseases	0.00109(0.00000, 0.00221)	0.01279
	Cardiovascular disease	0.00068(0.00043, 0.00093)	0.00989
Be ill	Chronic bronchitis	0.01009(0.00366, 0.01559)	0.00694
	Acute bronchitis	0.00790(0.00270, 0.01300)	0.03800
	Asthma	0.00210(0.00145, 0.00274)	0.05610

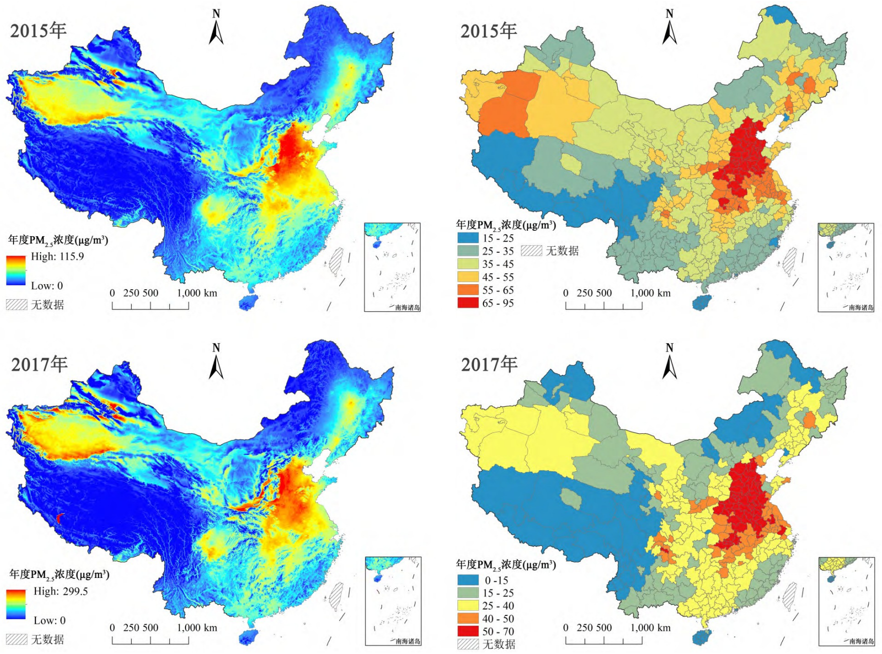
From the annual average $PM_{2.5}$ concentration, the environmental quality of $PM_{2.5}$ has improved to some extent, but the overall pollution pattern has not changed significantly. The highest value in 2015 was 91.378 in Hengshui City, hebei Province μg/m^3, the lowest value is 15.501 of Sanya, hainan μg/m^3, with an average of 45.737 μ g/m^3; the highest value in 2017 was 69.108 of Xingtai μg/m^3, the lowest value is 2.315 of Nagqu, tibet μg/m³, with an average of 32.959 μg/m³, and there are significant differences between regions. Among them, in 2015, it exceeded the national secondary standard 35 μ There were 221 cities with a concentration of g/m³, accounting for 65.4% of the total sample, while 126 cities exceeded the standard in 2017, accounting for 37.5% of the total. From the perspective of distribution characteristics, pM2.5 concentration presents a ladder like distribution. The highest concentration is concentrated in Beijing Tianjin Hebei and surrounding cities, the second highest concentration is mainly distributed in cities in the central and southwest regions, followed by scattered distribution in a few high-value cities such as northeast China and Xinjiang. Below 35 μg/m³. The low value area is mainly distributed in most cities of Tibet, qinghai and Yunnan in the southwest, southeast coastal areas and cities close to the national border in the northeast. The medium concentration area is mainly distributed in the buffer zone between the high value area and the low value area. Compared with the monitoring data obtained by the monitoring station, the annual average concentration of the remote sensing interpretation data is relatively low, especially in the Beijing Tianjin Hebei region with the most serious pollution, but it also reflects the real average level of regional pollution, which is more consistent with the actual situation [2,5].

2.1.2 Spatial distribution characteristics of urbanization level

In order to understand the population distribution and exposure in each region, the remote sensing population density data that replaces the total population at the end of the year will be selected for visual processing. Considering the similarity of space and the overall pattern of population distribution, this paper takes 2017 as an example. As shown in Figure 2, the left side is 1 km in 2017 × Remote sensing map of population density distribution with an accuracy of 1 km. The middle is the spatial distribution map of urban level after zoning statistical processing, and the right is the spatial distribution map of urbanization rate. Based on the results in Figure 1, it can be found that 75% of the urban population was exposed to the environment with PM2.5 pollution exceeding the national secondary standard in 2015, while this proportion decreased to 49.2% in 2017, with a significant decrease in the risk exposed population.

As can be seen from Figure 2, the population distribution in the east of huhuanyong line is relatively dense, while the population distribution in most cities in the west of huhuanyong line is sparse. In particular, the population density in the Middle East and eastern coastal areas is among the highest in China, while the population distribution in urban agglomerations and surrounding areas in inland areas centered on large cities such as provincial capitals is relatively dense. This distribution feature is similar to the PM2.5 concentration distribution feature in Figure 1, that is, most densely populated areas are also areas with serious air pollution, such as Beijing Tianjin Hebei region, chengdu Chongqing region and Central Plains urban agglomeration. However, there is no significant ladder distribution in the spatial distribution of population. Relatively speaking, the distribution of areas with high population density is relatively loose, and they are scattered around the big cities in flakes to the east of huhuanyong line. Therefore, it is necessary to combine PM2.5 concentration and population density distribution to quantitatively calculate the subsequent changes of health terminals exposed to polluted air.

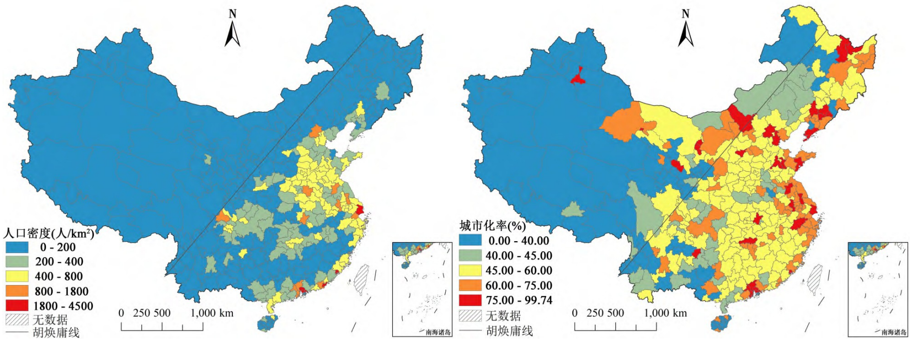
There are some similarities and differences between the distribution of urbanization rate and population density. The similarity is reflected in the fact that most of the cities that exceed the national average are eastern coastal cities and inland provincial capitals, especially Beijing, shanghai, shenzhen, guangzhou and other mega cities, and the urbanization level is in the forefront of the country. The difference is mainly reflected in two aspects: first, the cities in eastern and eastern provinces such as Shandong and Henan have a relatively low level of urbanization despite their high population density; second, some cities in western provinces and regions, such as Karamay City, wuhai City, jiayuguan City, etc., have a high urbanization rate due to their special population distribution structure or high industrialization level, but these cities have a wide land area and relatively low population density. Urbanization rate is an indicator that can comprehensively reflect the level of urban development. Urbanization has brought about population agglomeration. Due to population agglomeration and changes in lifestyle, the demand of urban population for food, clothing, housing and transportation has further expanded, which has accelerated the development of construction industry and the increase of motor vehicles, and exacerbated urban living air pollution [40].



Annual $PM_{2.5}$ Concentration

No data

Fig. 1 Spatial distribution characteristics of $PM_{2.5}$ Concentration in 2015 And 2017



Population density
No data
Huhuanyong line

Fig. 2 The population density and urbanization rate distribution in 2017

2.1.3 Relationship between $PM_{2.5}$ Concentration and population density and urbanization

Previous studies have pointed out that the continuous promotion of urbanization has intensified population and industrial agglomeration, which has not only promoted economic development, but also brought about "urban diseases" such as traffic congestion, increased exhaust emissions and environmental pollution [41-42]. In order to analyze the relationship between the three, this paper chooses to fit the urbanization rate and population density in 2015 and 2017 respectively with the concentration of $PM_{2.5}$, which is divided into low concentration stage (left) and high concentration stage (right) (Fig. 3).

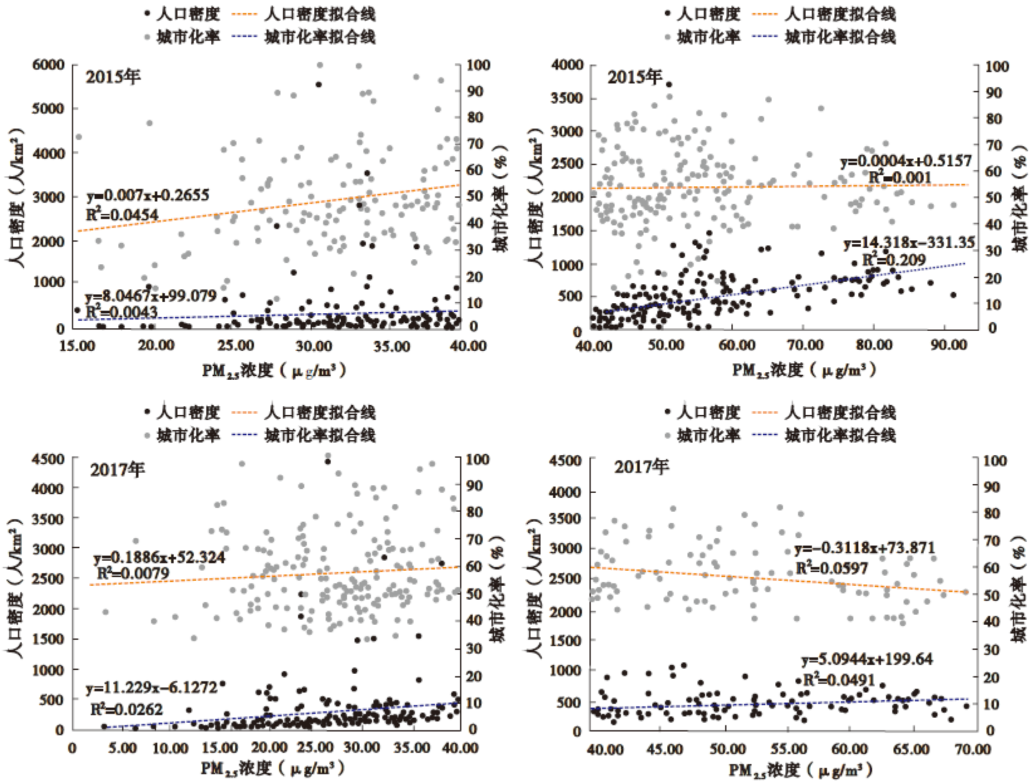
On the whole, in the two years, $pM_{2.5}$ pollution has a certain correlation with urbanization and population density, but the significance level is generally low, especially the fitting of population density in the low concentration stage and the fitting of urbanization rate in the high concentration stage. Relatively speaking, the fitting correlation between urbanization in 2015 at the stage of low concentration pollution and population density at the stage of high concentration pollution is highly significant, which means that most of the heavily polluted areas are densely populated, increasing the risk of population exposure. However, in 2017, the fitting significance of population density and urbanization rate at the stage of high concentration pollution was further reduced, which means that the $PM_{2.5}$ treatment effect of some high pollution and high urbanization cities (such as Beijing, tianjin, etc.) Began to show initially. But at the same time, cities with high urbanization rate are also faced with problems such as high medical consumption per unit and large loss of migrant workers. Therefore, it is necessary to deeply explore the impact of $PM_{2.5}$ pollution on people's health, analyze the relationship between urbanization and health impact and economic loss, and more intuitively reveal the difference in economic loss caused by $PM_{2.5}$ pollution under different urbanization levels, so as to start from the dimension of residents' health, divide priority cities and key areas for air pollution prevention and control.

2.2 $PM_{2.5}$ Pollution health and economic losses in the process of Urbanization

2.2.1 Health terminal impact assessment based on exposure response function

First, the above $PM_{2.5}$ concentration data and population data are substituted into formula (1), the changes of health terminals including premature death and illness caused by $PM_{2.5}$ pollution in 338 cities are calculated, and the top 20 cities are selected to draw a histogram (Figure 4). In terms of the overall number, the number of premature deaths and health losses caused by $PM_{2.5}$ pollution decreased from 4.967 million in 2015 to 3.779 million in 2017, a decrease of 23.9%. Among them, chronic bronchitis and asthma account for more than 26% of the total number of people with health impairment, followed by premature death and respiratory diseases, accounting for about 16%~18% of the total number of people with health impairment, while the number of health losses caused by acute bronchial and cardiovascular diseases is relatively small.

From the change of health terminals in the top 20 cities, the areas where $PM_{2.5}$ pollution causes illness or early death mainly occur in Beijing, tianjin and Hebei and some cities in Henan and Shandong around them, chengdu Chongqing urban agglomeration (especially Chongqing and Chengdu) and densely populated areas in the Yangtze River Delta. Some provincial capitals such as Wuhan, jinan, nanjing and other cities are also areas with significant changes in health terminals, the top four cities are Beijing, chongqing, shanghai and Tianjin. At the same time, these cities and regions are also the main air pollution key control areas with high $PM_{2.5}$ concentration. It can be seen that the dense distribution of population and the change of $PM_{2.5}$ concentration jointly affect the change of health terminal. However, relatively speaking, the impact of pollutant concentration changes is more significant. For example, although the southeast coastal cities and the Pearl River Delta are also densely populated areas, the health terminal changes are not very significant due to the low pollution concentration. In addition, from 2015 to 2017, the number of premature deaths and health losses caused by $PM_{2.5}$ pollution in the top 20 cities also decreased significantly, but the overall pattern of damaged cities has not changed. Among them, 18 cities are still among the top 20 key loss areas, cangzhou in Hebei and Weifang in Shandong dropped to No. 20 in 2017, and the ranking of health losses in some cities is improving, it shows that the air pollution control and health loss improvement in these key cities need to be continuously strengthened.



●	Population density
●	Urbanization rate
-----	Population density fitting line
-----	Urbanization rate fitting line

Fig. 3 The fitting relationship between $PM_{2.5}$ Concentration and population density & urbanization in 2015 And 2017

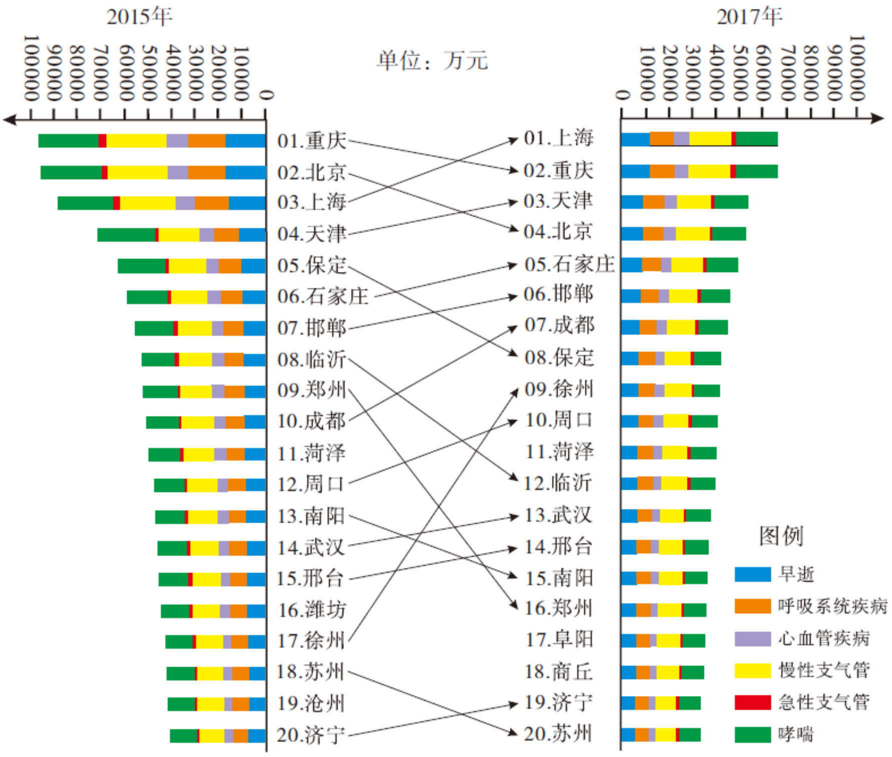
2.2.2 Economic loss accounting of health risk

The impact of the reduction of effective labor supply caused by the early death of air pollution on the economy should not be ignored, followed by the hospitalization of related diseases, because these health terminals lead to the loss of labor time, and the reduction of labor time supply will inevitably have an impact on the economy. Air pollution will further aggravate the scarcity of labor. The related economic losses caused by the reduction of labor time and labor supply have reached 0.6%~2.8% of GDP[43]. Therefore, it is necessary to clarify the related economic losses.

The accounting basis and process of unit economic losses of different health terminals are as follows: a. the unit economic losses caused by early death are calculated by using the value of life method and the proportion of disposable income with reference to Beijing residents [44]. b. Outpatient loss and inpatient loss are calculated by disease cost method. The daily average value of annual per capita GDP is taken as the per capita daily lost work cost, and the lost work time is the hospital stay. c. The course of chronic bronchitis is slow, it is generally difficult to recover, and the time of illness is difficult to determine, which often causes great pain to patients and significantly reduces the quality of life of patients. Therefore, it is not appropriate to use the disease cost method to calculate the unit cost. This paper takes the intermediate value of the research results of Viscusi et al. [45] and Chenxiaolan [46], that is, the unit cost of chronic bronchitis is 40% of the statistical life value. For the unit economic loss of acute bronchitis and asthma, the unit loss of acute bronchitis and asthma in each city is estimated according to the ratio of the disease treatment cost of Huang Desheng et al. [20] to the unit loss of acute bronchitis and asthma, combined with the disease treatment loss of each province and the per capita disposable income of each city.

Based on the above health terminal changes and unit economic losses, the economic losses caused by health problems caused by $PM_{2.5}$ pollution and the total economic losses caused by changes in all health terminals in various cities in 2015 and 2017 are calculated. In order to facilitate more intuitive observation and analysis, the calculation results of economic losses caused by total economic losses are visualized. The results are shown in Figure 5. From a numerical point of view, the national total economic loss in 2017 was 1382.64 billion yuan (accounting for 1.68% of the total GDP of that year), a decrease of 24.24% compared with the total economic loss of 1824.96 billion yuan (accounting for 2.65% of the total GDP of that year) in 2015, indicating that with the slowdown of air pollution, the health economic loss of residents is also significantly reduced. In 2017, the total loss of health terminals nationwide was 860.49 billion yuan for premature death, 4.228 billion yuan for hospitalization for respiratory diseases, 4.13 billion yuan for hospitalization for cardiovascular diseases, 507.81 billion yuan for chronic bronchitis, 210 million yuan for acute bronchitis and 5.77 billion yuan for asthma, respectively, up from 2015

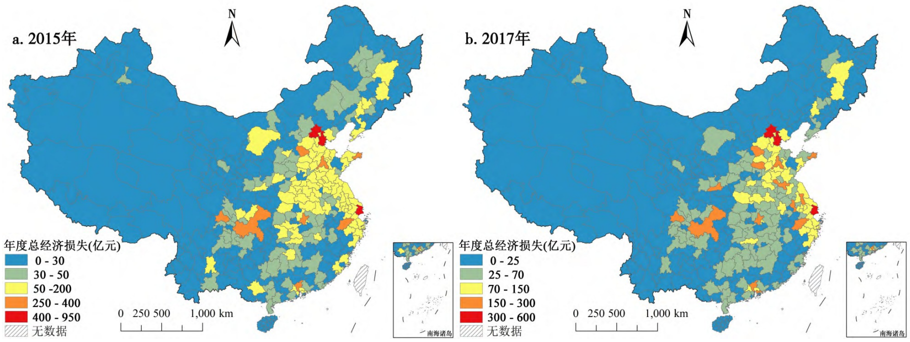
Figure 4 the top 20 cities in terms of health loss of residents in 2015 and 2017 decreased by 24.23%, 24.57%, 24.55%, 24.23%, 24.67% and 24.41% compared with the previous years. In terms of breakdown, according to different health terminals, premature death and chronic bronchitis, which cause permanent or long-term loss of labor, cause the most economic losses, followed by hospitalization for diseases, because such diseases not only require treatment costs, but also include the cost of lost work caused by hospitalization.



Chongqing	Shanghai	🟦	Premature death
Beijing	Chongqing	🟧	Respiratory diseases
Shanghai	Tianjin	🟪	Cardiovascular disease
Tianjin	Beijing	🟨	Chronic bronchi
Baoding	Shijiazhuang	🟥	Acute bronchi
Shijia	Handan	🟩	Asthma
Handan	Chengdu	Legend	
Linyi	Baoding		
Zhengzhou	Xuzhou		
Chengdu	Zhoukou		
Heze	Heze		
Zhoukou	Linyi		
Nanyang	Wuhan		
Wuhan	Xingtai		
Xingtai	Nanyang		
Weifang	Zhengzhou		
Xuzhou	Fuyang		
Suzhou	Shangqiu		
Cangzhou	Jining		
Jining	Suzhou		

Fig. 4 Line chart of health terminal change in 2015 And 2017 (top 20 Cities)

From the spatial distribution characteristics in Figure 5, in general, high-value areas are mainly distributed in Beijing, tianjin, hebei and surrounding cities, as well as Shanghai, chongqing, chengdu, guangzhou and other large cities with dense population and rapid economic development. However, there are huge differences in the difference of economic losses between cities. The losses of high-value areas are hundreds or even thousands of times that of low-value areas. In 2015, the top ten cities in terms of total economic losses were Beijing, shanghai, tianjin, chongqing, suzhou, shijiazhuang, wuhan, chengdu, guangzhou and Hangzhou, accounting for 21.8% of the total losses in China. The Beijing Tianjin Hebei and surrounding areas, yangtze River Delta and Pearl River Delta Urban Agglomerations where these 10 cities are located are also the key areas for air pollution control in China, which also shows that air pollution in large cities and megacities brings more health damage and economic losses, and also means that strengthening the effective control of air pollution in large cities can reduce the economic losses of residents.



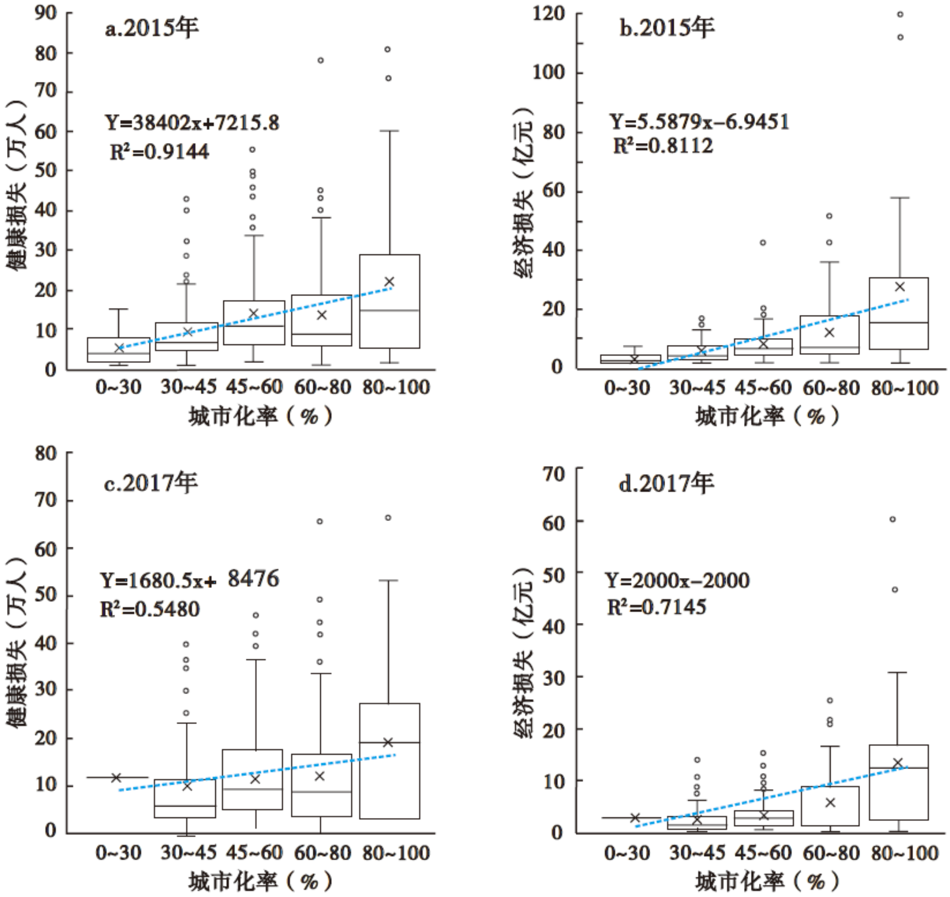
Annual total economic loss
No data

Fig. 5 Spatial distribution of economic loss in 2015 And 2017

2.2.3 Health problems and economic losses under different urbanization levels

In order to explore the differences in health problems and economic losses caused by air pollution at different urbanization levels, combined with fangchuanglin's division of China's urbanization development stages [47], the urbanization rate is divided into five stages (<30%, 30%~45%, 45%~60%, 60%~80% and >80%), box charts of health terminal losses and economic losses in 2015 and 2017 are drawn respectively (Figure 6), and the average values of different stages are fitted and analyzed.

First, on the whole, the increase of population urbanization rate has a great impact on the health problems and corresponding economic losses caused by $PM_{2.5}$ pollution (the fitting significance level decreased slightly in 2017), and this impact is more significant than the pollution concentration itself. As can be seen from the health loss correlation diagram on the left side of Figure 6, with the increase of urbanization rate, the minimum value of each stage changes little, but the maximum value changes significantly, and the average value increases with the increase of urbanization rate. For economic loss, the change is similar to that of health loss. This shows that in the stage of low urbanization rate, due to underdeveloped economy, small urban scale and insignificant agglomeration effect, cities have better environmental quality, lower health and economic losses, and smaller differences among cities. However, at the stage of high urbanization rate, there are great differences in health loss and economic loss among cities, indicating that in cities with high urbanization rate, the differences in industrial structure, pollution policy, geographical environment, etc. Make the differences in health and economic loss caused by pollution significant. Therefore, for some cities with high pollution and high population urbanization rate (such as Beijing, tianjin, etc.), it is necessary to pay special attention to the health loss of residents caused by air pollution, take active countermeasures, and improve the medical security system and haze removal technology support system; for some cities with low pollution and high population urbanization rate (such as Shenzhen, zhuhai, etc.), it is necessary to maintain the current good development trend of urbanization, optimize the industrial structure and layout, and achieve green and high-quality economic development.



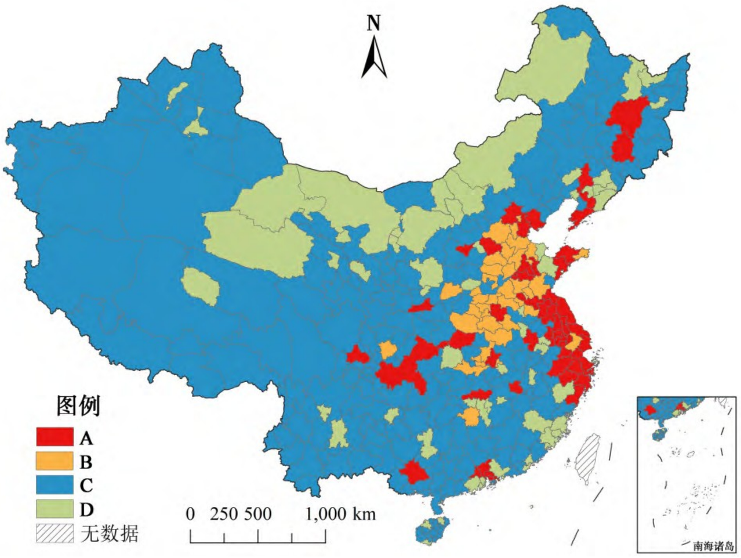
Urbanization rate
Health loss (10000 Persons)
Economic losses (100 Million yuan)

Fig. 6 Correlation between urbanization rate and health as well as economic losses caused by $PM_{2.5}$ Pollution

2.3 Policy enlightenment and suggestions

First, adopt different $PM_{2.5}$ pollution zoning treatment strategies to effectively control the health and economic losses of residents caused by pollution. Taking into account the difference in economic losses caused by $PM_{2.5}$ pollution under different urbanization levels, this paper classifies the situations of cities at various levels based on the data in 2015, with the data in 2017 as the reference, with the urbanization rate as the horizontal axis, the total economic losses of prefecture level cities as the vertical axis, and the intersection of the horizontal and vertical coordinates as (0.56, 7.5) (the average value of the national 388 urbanization rate is 0.56 and the average value of the urban economic losses is 7.5 billion yuan) (Figure 7).

Specifically, it includes the following four types: a. quadrant I refers to high-rise cities of type A. These regions are densely populated, exposed to relatively serious pollution environment, and have more economic losses than other regions due to their relatively developed economy. They are the cities that need the most attention and key control. In 2015, there were 51 class a cities, including 19 provincial capitals and municipalities directly under the central government. In 2017, the number dropped to 45. The urbanization rate in these areas is high, and the residents live in cities. The centralized production and life style leads to serious environmental pollution and prominent health problems. The top ten cities with economic losses accounted for 21.8% of the total loss value of the country, and the urbanization rate was higher than the national average. b. The second quadrant is type B low and high cities. Although the urbanization level of this type of cities is low, they still have serious $PM_{2.5}$ pollution and economic losses. Many of these cities are distributed around type a cities. Although their urbanization level is low, their industrial output value accounts for a relatively high proportion, and most of them are high pollution and high energy consumption industries (15 of the 34 cities account for more than 50% of the output value of the secondary industry, especially Tongling, pingdingshan, weifang and other famous resource-based cities or heavy industrial cities). The emission of air pollutants is large. At the same time, some cities have also undertaken the high pollution and high energy consumption industries eliminated in the process of urbanization in neighboring big cities. In addition, due to the air mobility and the spatial spillover effect of pollutants, the air quality of these cities is affected by the surrounding type a cities, resulting in health losses and corresponding economic losses. c. Quadrant III refers to the low-level cities of type C. The urbanization level and economic losses in these areas are lower than the national average level. They are areas with low urbanization rate but less pollution and economic losses, and are not key areas. However, in order to avoid the outward diffusion of type A and B agglomeration areas, class C cities distributed around cities a and B must pay special attention to the spatial spillover effect of pollution and the transfer of industries with high pollution and high energy consumption, so as to avoid damaging the urban environmental quality and residents' health in the process of urbanization development and construction. d. Quadrant IV refers to type D high and low cities, which are areas with high urbanization level but low economic losses. These cities should become successful examples of air pollution control. Some of these cities are significantly affected by good weather and natural factors. For example, the coastal areas have better pollution diffusion advantages, which makes some large cities such as Xiamen, zhongshan and Zhuhai have better air quality and smaller health losses. However, other cities distributed in inland areas can analyze their industrial structure, environmental policies, urban layout and other characteristics in detail, in order to provide a positive model for air pollution control in the development process of other cities. Such cities need to continue to maintain the good situation of air pollution control and strive to become a model city for healthy China and the construction of ecological civilization.



Legend
No data

Fig. 7 Zoning of PM$_{2.5}$ Pollution and economic loss in 2015

Second, we should strengthen pollution control in key areas, appropriately control population size, optimize population distribution, reduce particulate matter and other emissions on the consumer side, and effectively improve the health and well-being of residents. For the above-mentioned class a key control areas, we should first strengthen the monitoring and treatment of urban pollution, check the implementation of emission reduction measures, the completion of key projects and the construction and operation of monitoring and monitoring system, and consider using economic punishment, administrative interview and other means to deal with the responsibility for illegal emissions. At the same time, due to the large urban population density, the pollution emissions from urban traffic sources and living sources are also increasing rapidly. Therefore, it is necessary to strengthen the control of motor vehicle and living source pollution. In terms of public health, the forecast and protection of smog are also more important, such as guiding urban residents to carry out effective physical protection in smog weather. In terms of the medical and health system, it is necessary to increase the level of medical services and security for related diseases such as bronchitis and asthma, so as to reduce the cost of treatment for these diseases. For type B cities, it is necessary to raise the industry access threshold for new enterprises, use the forced mechanism to curb the unrestrained demand of new projects for pollution discharge indicators, and constantly optimize the industrial structure. At the same time, we should mobilize the enthusiasm of existing enterprises in pollution control, rely on technological progress and optimization of energy structure, so as to improve the level of environmental capacity and the efficiency of resource allocation.

In addition, in the future, it is also necessary to continuously accelerate the improvement of the high-quality development level of cities, promote the development and promotion of green and low-carbon innovative technologies with intelligent and green production and lifestyle, so as to effectively reduce the cross-border transfer of pollution and realize the coordinated management of air pollution among cities.

3 Conclusion

a. From 2015 to 2017, china's $PM_{2.5}$ environmental quality has improved to some extent, but the overall pollution pattern has not changed significantly. The average concentration of $PM_{2.5}$ increased from 45.737 in 2015 μg/m^3 decreased to 32.959 in 2017 μg/m^3, the proportion of polluted cities exceeding the national secondary standard decreased from 65.4% in 2015 to 37.5% in 2017. High pollution areas are mainly distributed in Beijing Tianjin Hebei and surrounding cities.

b. From 2015 to 2017, the exposed population, health terminal losses and economic losses caused by $PM_{2.5}$ pollution decreased significantly. Among them, the number of premature deaths and health losses decreased from 4.967 million in 2015 to 3.779 million in 2017, a decrease of 23.9%; the total economic losses of residents decreased from 1824.96 billion yuan in 2015 to 1382.64 billion yuan in 2017, a decrease of 24.24%.

c. The increase of urbanization rate has a great impact on the health problems and corresponding economic losses caused by $PM_{2.5}$ pollution, especially in some high pollution and high urbanization cities such as Beijing, tianjin and Hebei. Based on the urbanization rate and economic losses, 388 cities in China are classified into type a high and high cities (key control areas), type B low and high cities (potential high-risk areas), type C low and low cities (non key control areas) and type D high and low cities (successful model areas). At present, the cities most in need of monitoring and governance are class a cities, which have a high level of urbanization and high health risks and economic losses. Active response measures should be taken and the medical security system and haze removal technology support system should be improved.

Compared with existing studies, this paper reveals the relationship between $PM_{2.5}$ pollution and residents' health loss and economic loss under the influence of different urbanization levels on the basis of population density, urbanization and pollutants, making the analysis results more intuitive. However, taking the economic loss as the evaluation standard, the residents' right to life and health is ignored. The follow-up research can further explore the economic loss of air pollution caused by different living habits, exposure patterns, consumption ideas, etc. From the perspective of residents' willingness to pay, in combination with the residents' income level, medical and health security system and other factors under the development of different urbanization levels. In addition, with the promotion of the multi-objective coordinated and comprehensive treatment of $PM_{2.5}$, ozone, air pollution and carbon emissions in China, it is necessary to pay attention to the comprehensive impact of ozone and other pollutants on human health, ecological effects and economy in the future.

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