ISSN 1746-7659, England, UK
Journal of Information and Computing Science
Vol. 17, No. 2, 2022, *pp*.083-101

Health and Economic Loss Assessment of Haze Pollution in "2+26" Cities in the Air Pollution Transmission Channel

Lushuang Xiao and Guizhi Wang[1]
School of Mathematics and Statistics, Nanjing University of Information Science & Technology, Nanjing 210044, China
(Received August 12, 2022, accepted October 29, 2022)

Abstract: Based on the annual average $PM_{2.5}$ concentration data, economic data and health data from 2017 to 2020 in 2+26 cities, we evaluated the health effects and health and economic losses attributable to $PM_{2.5}$ pollution in eight health end points (premature death, outpatient visit, hospitalization and illness). The results showed that the average annual $PM_{2.5}$ concentration, health effects of each disease, economic loss, total health effects and total economic loss in 2+26 cities gradually decreased from 2017 to 2020, but the health effects and economic loss in some cities increased in 2020. The health endpoints with the highest economic losses were chronic bronchitis and premature death, followed by acute bronchitis, asthma, asthma, and asthma, followed by acute bronchitis, asthma, cardiovascular disease, and respiratory hospitalizations, and finally pediatrics and internal medicine. Based on the above results, the reduction o $PM_{2.5}$f concentration was the main reason for the reduction of health effects and health economic effects attributed to $PM_{2.5}$ in 2+26 cities. There is still room for further reduction of $PM_{2.5}$ pollution in each city. Therefore, cities can still take corresponding measures to control $PM_{2.5}$ pollution in the future to reduce health benefits and health economic benefits caused by $PM_{2.5}$. However, we also found that the reduction of health effects and health economic effects and the magnitude of reduction differed greatly among cities with different levels of development. Therefore, for some cities with a low level of economic development, they are facing the pressure of economic development and the pressure of reducing pollution. How to achieve the effect of reducing haze pollution while developing the economy is the problem that these cities need to solve at present.

Keywords: $PM_{2.5}$; Economic losses; Atmospheric contamination; Transmission path.

1. Introduction

Some substances produced by human activities and natural processes, after entering the atmospheric environment, remain at a certain concentration level and exist in the atmosphere for a sufficient time, which will affect human life and cause certain harm to human health and the environment [1,2].

Air pollution is mainly caused by human activities. In the process of production activities and winter heating in secondary industry factories, the burning of fossil fuels will emit particulate matter into the atmosphere [3,4]. In addition, vehicle exhaust emissions are also an important source of air pollutants [5]. Once atmospheric pollutants enter the atmospheric environment, they may exist in the atmosphere for a long time due to natural meteorological conditions and natural geographical environment factors, thus causing harm to human health [6,7]. Studies have shown that air pollutants may cause cardiovascular diseases, respiratory diseases, and even death in severe cases [8,9,10].

In order to control air pollution, our country has issued a series of policies and taken a series of measures. In September 2013, The State Council issued the Action Plan for Air Pollution Prevention and Control, which adopted measures such as desulfurization, denitrification, and dust removal in key industries, promotion of new energy vehicles, and optimization of industrial structure and energy structure, aiming to improve the overall air quality of the country and reduce heavy pollution weather. In March 2016, the Standing Committee of the National People's Congress proposed in the Outline of the 13th Five-Year Plan for National Economic and Social Development that each city should designate a plan to meet air quality standards, reduce the number of days with moderate pollution, and have more than 80% of the days with good air quality. In March 2017, the Beijing-Tianjin-Hebei region and surrounding areas, including Beijing, Tianjin City, Hebei province, Shanxi Province, Shandong Province, and Henan province, were the air

[1] Corresponding Author *E-mail*:wgz@nuist.edu.cn.

pollution transmission channel cities. In the 2017 Work Plan for the Prevention and Control of Air Pollution in Beijing-Tianjin-Hebei and Surrounding Areas issued by the Ministry of Environmental Protection, the above cities will be implemented with separate emission limits to further strengthen the rectification of these areas and gradually promote the adjustment of industrial structure. In the same year, the Action Plan for Comprehensive Air Pollution Control in Autumn and Winter of 2017-2018 proposed to ensure the full completion of the assessment criteria for the Air Pollution Prevention and Control Action Plan. The Three-year Action Plan to Win the Blue Sky Defense was released at the end of June 2018, which focused on continuing air pollution prevention and control in the Beijing-Tianjin-Hebei region and its surrounding areas, the Fenwei Plain, and the Yangtze River Delta, and proposed total emission limits for carbon dioxide and nitrogen oxides nationwide. In addition, under the instructions of the central government, local governments have also introduced relevant policies and documents to specify air pollution control measures.

When studying the assessment of economic losses caused by haze pollution, domestic and foreign researchers often use methods such as human capital method, willingness to pay method, disease cost method, statistical life value method and scenario analysis method. Burtraw et al. [11] used the power market equilibrium model named Haiku and the Model Tracking and Analysis Framework (TAF) of the Comprehensive assessment of Atmospheric Transport and Environmental impact to study the auxiliary benefits of greenhouse gas emission reduction policies in the power sector of the United States from 2000 to 2010. Shi[12] used Cox equivalent Poisson models and parallel computing to estimate the hazard ratio (HR) for first hospitalization for Parkinson's disease or Alzheimer's disease and related dementia, and found that exposure to annual average $PM_{2.5}$ was significantly associated with increased risk of Parkinson's disease, Alzheimer's disease, etc., in the United States. Domestic scholars have evaluated different regions of the country [13,14]. Most of the assessment focused on the Beijing-Tianjin-Hebei region, but there are other areas as well.Wang et al. [15] used the exposure response model to quantify the negative health effects of $PM_{2.5}$ pollution in Beijing in 2013, established a CGE model to simulate the exogenous impact of $PM_{2.5}$ pollution on the national economic system, and calculated that the GDP loss was 901 million CNY. Han[16] evaluated the health benefits of prevention and control of PM_{10} and $PM_{2.5}$ pollution in Zhengzhou from 2014 to 2016.Wu[17] evaluated the number of deaths attributed to long-term $PM_{2.5}$ exposure and its corresponding health and economic losses in the Beijing-Tianjin-Hebei region in 2015. Chen[18] used Poisson regression model to estimate the public health impact and economic loss of $PM_{2.5}$ pollution caused by coal consumption by using the data of 2015, and predicted the public health impact and economic loss of $PM_{2.5}$ pollution caused by coal consumption in 2020 and 2030. Dong[19] used the exposure response model to measure the health loss, and used the revised human capital method, willingness-to-pay method and disease cost method to calculate the economic loss, and found that $PM_{2.5}$ pollution had a significant impact on the health effect and economic loss of the Fenwei Plain. Fan[20] used a log-linear expose-response function to estimate the health impacts of PM_{10} in the Beijing-Tianjin-Hebei region in 2016, and found that the health economic losses caused by air pollution accounted for 1.32%, 0.97% and 1.74% of the local GDP in Beijing, Tianjin and Hebei. Wang[21] proposed a health-related economic loss assessment system, simulated the $PM_{2.5}$ concentration characteristics of three cities in the Beijing-Tianjin-Hebei region, and estimated the economic loss of the Beijing-Tianjin-Hebei region. Chen[22] discussed the establishment of ecological compensation mechanism and constructed a model to measure the economic loss of residents. Li[23] estimated the health effects and health economic losses caused by $PM_{2.5}$ in 297 cities at the prefecture level and above in China from 2015 to 2018, and found that the health economic loss decreased from 15790.39 billion CNY to 838.416 billion CNY, and the proportion of health economic loss in GDP decreased from 2.31% to 0.99%. Xu[24] evaluated the health economic loss caused by $PM_{2.5}$ pollution in the Beijing-Tianjin-Hebei region from 2013 to 2018 and found that the health economic loss caused by $PM_{2.5}$ pollution in the Beijing-Tianjin-Hebei region showed a downward trend year by year from 2013 to 2018. Wang[25] evaluated the health economic loss of "2+26" cities in 2020, and found that the economic loss showed a spatial distribution characteristics of high in the east and low in the west, and put forward corresponding policy recommendations on this basis. Zhao[26] evaluated the effect of "2+26" cities after adopting corresponding emission reduction policies from 2015 to 2018, and concluded that the concentration of each pollutant had decreased, and the health and economic losses caused by air pollution had been reduced.

The existing research results mainly focus on the Beijing-Tianjin-Hebei region, and there are few studies on 2+26 cities. The loss assessment in a period of time has not been updated. Therefore, this paper based on the existing research, Based on the air pollution transmission channel cities in Beijing-Tianjin-Hebei region identified in the 2017 Work Plan for Air Pollution Prevention and Control in Beijing-Tianjin-

Hebei Region and surrounding Areas issued by the Ministry of Environmental Protection in 2017, we evaluated the health effects and health economic effects attributable to $PM_{2.5}$ in the "2+26" cities from 2017 to 2020. To assess the overall distribution and changes of health effects and health economic effects in "2+26" cities.

2. Data and Methodology

2.1. Method

2.1.1. Assessment of health effects

Exposure-response relationship, which reflects the quantitative relationship between population exposure and health effects, is usually used in combination with Poisson regression relative risk models to assess the health effects of environmental pollution. It is calculated as follows:

$$R = R_0 \cdot e^{\beta(c-c_0)} \tag{2.1}$$

$$\Delta R = R - R^0 = R^0 \cdot \left(1 - \frac{1}{e^{\beta(c-c_0)}}\right) \tag{2.2}$$

$$\Delta HE_{i,t} = P \cdot \Delta R_{i,t} = P \cdot R_{i,t}^0 \cdot \left(1 - \frac{1}{e^{\beta_i(c-c_0)}}\right) \tag{2.3}$$

Here, c is the actual pollutant concentration, c is the benchmark concentration of the pollutant, this paper chooses the secondary concentration limit of the pollutant concentration, $35\,\mu g/m^3$ as the benchmark concentration, R is the health risk of the population exposed to the actual concentration, R_0 is the health risk at the benchmark concentration, is the benchmark incidence of the corresponding disease terminal. ΔR is the change in the relative risk of health effects due to increasing pollutant concentrations. P is the number of people exposed to the pollutant. i is the ith health terminal, t is year t, $\Delta HE_{i,t}$ is the pollutants in t corresponds to the health of terminal i effect change, reflects the impact of pollutants of exposed workers.

2.1.2. Environmental health value assessment

This paper discusses the health economic value of air pollution transmission channel cities based on four aspects: premature death, outpatient service, hospitalization, and illness. The health endpoints corresponding to outpatient department were pediatrics and internal medicine, the health endpoints corresponding to inpatient department included respiratory disease, cardiovascular disease and asthma, and the diseases corresponding to illness were acute bronchitis and chronic bronchitis. There were eight health endpoints including premature death.

The health economic value of environmental health includes the economic loss from premature death and the cost of treatment due to disease. Among them, the economic loss caused by premature death is evaluated based on the statistical life value method [27]. This paper is based on the research results of Beijing in 2010 [28], and uses the benefit transformation method [29] to measure the statistical life value of Beijing in other years and the statistical life value of other cities with air pollution transmission channels except Beijing. The specific methods are as follows:

$$VSL_t = VSL_{t_0} \times (1 + r_{CPI} + r_{GDP})^{\alpha} \tag{2.4}$$

$$VSL_{city} = VSL_{Beijing} \cdot \left(I_{city}/I_{Beijing}\right)^{e} \tag{2.5}$$

Among them, the first equation is used to calculate the statistical life value of other years in Beijing, VSL_t represents the statistical life value of Beijing in year t, VSL_{t_0} represents the statistical life value of Beijing in year t_0, r_{CPI}I and r_{GDP} are the CPI of consumer price index and the growth rate of per capita GDP in Beijing from year t_0 to year t. The second equation is used to calculate the statistical life value of other air pollution transmission channel cities except Beijing. VSL_{city} and $VSL_{Beijing}$ are the statistical life value of other cities and Beijing, respectively. I_{city} and $I_{Beijing}$ are the per capita disposable income of other air pollution transmission channel cities and Beijing, respectively. α and e for income elasticity.

The disease cost method was used to evaluate the treatment costs caused by diseases, which mainly refers to the diseases caused by environmental pollution, the outpatient treatment costs, medical costs, hospitalization costs and the loss of work costs caused by the treatment of diseases. The direct loss refers to the average medical cost of outpatients and inpatients, including medical expenses and treatment costs, and the indirect loss refers to the loss of work due to outpatients and inpatients. Therefore, for each city, the unit costs of inpatient and outpatient disease terminals are estimated using the following formula:

$$cost_{i,t} = UC_{i,t} + PGDP_t \times T_i \tag{6}$$

Among them, $\mathbf{UC_{i,t}}$ represents the unit economic loss cost of disease terminal $\mathbf{i}$ in year $\mathbf{t}$, which is the average outpatient cost or average hospitalization cost, and $\mathbf{PGDP_t}$ represents the per capita GDP of the city in year $\mathbf{t}$. $\mathbf{T_i}$ represents the missed work time due to the treatment of disease terminal $\mathbf{i}$. For the outpatient clinic, the missed work time is set to 0.5 days; For hospitalization, missed work time was defined as days of hospitalization. $\mathbf{cost_{i,t}}$ is the unit cost of corresponding disease terminal $\mathbf{i}$ in the city in year $\mathbf{i}$.

For the health economic value of the health terminal, based on the outcome reference method, the treatment cost of acute bronchitis was calculated according to the method of Du[30], which was 4.85 times of the outpatient unit cost. Due to the long treatment cycle of chronic bronchitis, it is difficult to estimate the treatment cost. According to the conclusion of Viscusi et al. [31], 32% of the statistical life value is taken as the economic value of chronic bronchitis. The average days of hospitalization and medical expenses per unit of each health terminal were obtained based on China Health Statistics Yearbook.

2.1.3. Total health economic value assessment

Based on the unit economic value of each health terminal and the corresponding health effects, the total health economic value of each air pollution transmission channel city can be calculated as follows.

$$HV_t = \sum_{i=1}^{8} URV_{i,t} \cdot \Delta HE_{i,t} \tag{2.7}$$

The $\mathbf{HV_t}$ is the total health economic value of the city after controlling the concentration of $\mathbf{PM_{2.5}}$ pollutants in year $\boldsymbol{t}$, the $\mathbf{URV_{i,t}}$ is the corresponding health benefit of the city's health terminal $\boldsymbol{i}$ in year $\boldsymbol{t}$, and the $\mathbf{\Delta HE_{i,t}}$ is the health effect of the city's health terminal $\boldsymbol{i}$ in year $\boldsymbol{t}$.

2.2. Data

2.2.1. Air pollution transmission path

This article is in view of the atmospheric pollution of city transport channel is studied, thus collected 2+26 cities average annual $PM_{2.5}$ concentration. Since 2013, China's air quality has improved significantly. The average concentration of $PM_{2.5}$ in 2+26 cities decreased from 92.19 μg / m³ in 2013 to 27.12 μg / m³ in 2017. According to the figure1, from 2017 to 2020, the average annual concentration of $PM_{2.5}$ in 2+26 cities continued to decline. Especially from 2017 to 2018, the average concentration of $PM_{2.5}$ in 2+26 cities decreased from 65.07μg / m³ to 55.05μg / m³, with an average decrease of 10 μg / m³. In 2020, the annual average concentration of $PM_{2.5}$ in 2+26 cities had reached 51.25 μg / m³, but it was still far from the secondary limit of 35μg / m³ in National Standard for Atmospheric Environmental Quality. Data used in this paper are from the $PM_{2.5}$ historical data platform (https://www.aqistudy.cn/historydata/).

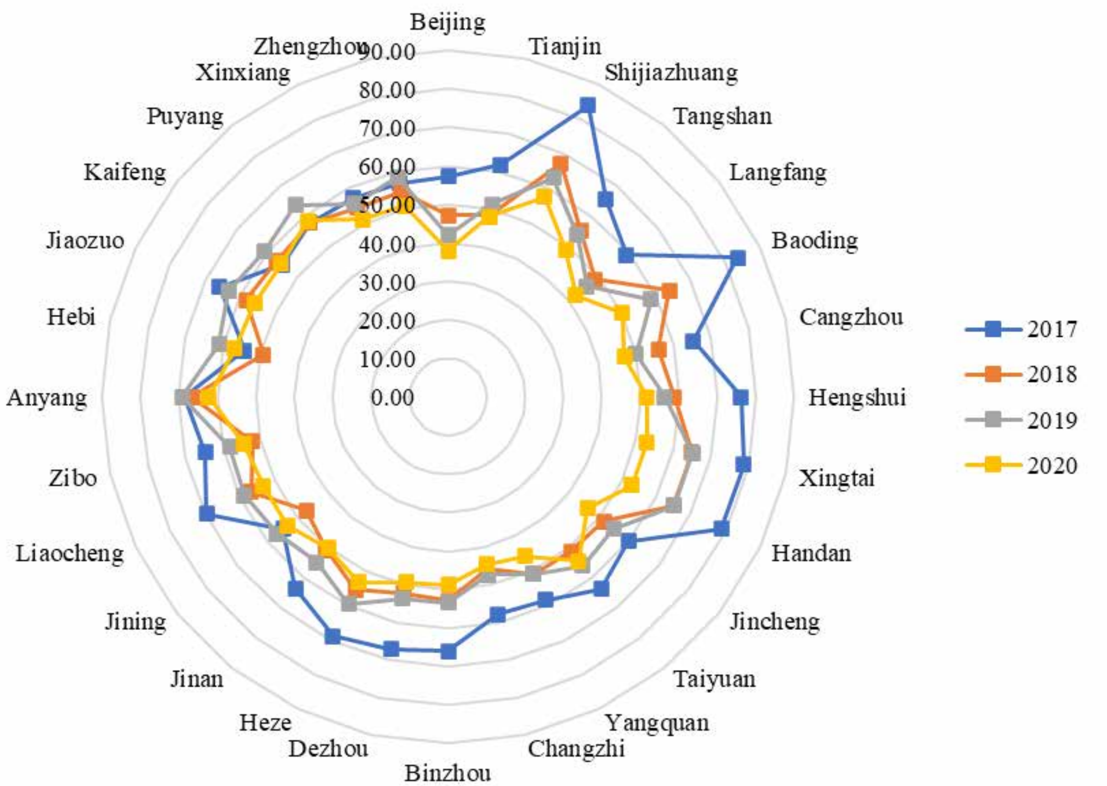

Fig. 1 2+26 cities annual average $PM_{2.5}$ concentrations from 2017 to 2020

According to the reduction of annual average $PM_{2.5}$ concentration in 2+26 cities (Figure 2), the annual average concentration of each city decreased the most from 2017 to 2018. From 2018 to 2019, the pollutant concentration of Beijing, Tianjin and Hebei decreased, but some cities in Shanxi, Shandong and Henan showed an increase instead of a decrease. The concentrations of pollutants in all cities decreased from 2019 to 2020.

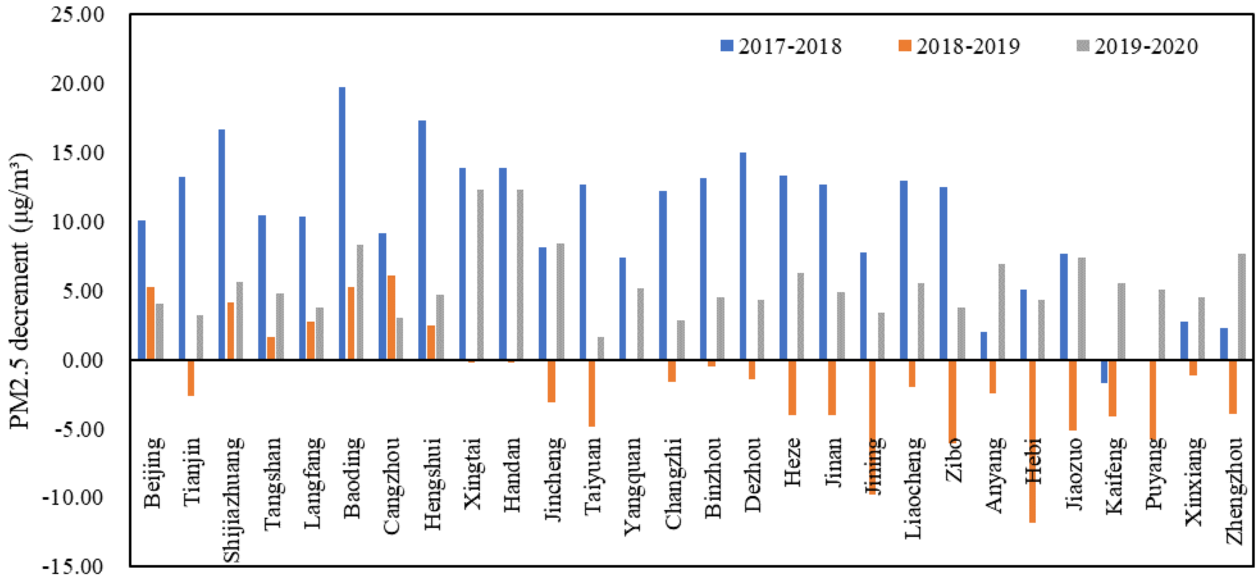

Fig. 2 Reduction in mean $PM_{2.5}$ concentration over the years

We used the annual average $PM_{2.5}$ concentration data in 2+26 cities from 2017 to 2020 to evaluate the health effects and economic losses caused by $PM_{2.5}$ in 2+26 cities since 2017. Based on the years average concentration data of $PM_{2.5}$, related economic data and health end treatment cost data, we evaluated the economic loss caused by $PM_{2.5}$ in 2+26 cities from 2014 to 2020. The concentration data of $PM_{2.5}$ in each city were obtained from different sources. The data of mortality rate, GDP, GDP per capita, CPI, and resident population at the end of the year were collected from the statistical yearbooks of cities from 2014 to 2020. The prevalence rate, per capita hospitalization cost and per capita outpatient cost were obtained from China Health Statistics Yearbook. The permanent resident population of each city is the exposed population group, and the data are shown in Table 1. The GDP per capita data are listed in Table 2. The per capita disposable income of each city is shown in Table 3.

Table 1. Permanent population in each city from 2017 to 2020

Unit: Ten thousand people

city	2017	2018	2019	2020	city	2017	2018	2019	2020
Beijing	2194.4	2191.7	2190.1	2189.0	Jinan	732.1	746.0	890.9	924.2
Tianjin	1410.0	1383.0	1385.0	1386.6	Zibo	470.8	470.2	469.7	470.6
Shijiazhuang	1088.0	1095.2	1103.1	1124.2	Jining	837.6	834.6	835.6	836.1
Tangshan	789.7	793.6	796.4	771.9	Dezhou	579.6	581.0	574.9	561.4
Langfang	474.1	483.7	492.1	548.6	Liaocheng	606.4	607.5	609.8	595.3
Baoding	1169.1	1173.1	1063.0	924.4	Binzhou	391.2	392.3	392.3	393.0
Cangzhou	755.5	758.6	754.4	730.2	Heze	873.6	876.5	878.2	879.9
Hengshui	446.0	447.2	448.6	421.1	Zhengzhou	1164.3	1205.2	1235.5	1261.7
Xingtai	735.2	737.4	739.5	710.9	Kaifeng	477.2	478.3	481.4	483.5
Handan	951.1	952.8	955.0	941.5	Anyang	532.9	537.1	543.0	547.6
Taiyuan	498.4	511.5	523.2	531.9	Hebi	153.3	153.4	155.9	156.8
Yangquan	132.6	132.3	132.1	131.8	Xinxiang	619.9	622.5	624.6	625.5
Changzhi	321.3	319.8	318.6	318.0	Jiaozuo	350.2	349.3	350.9	352.4
Jincheng	220.2	219.7	219.5	219.4	Puyang	378.4	374.9	374.2	377.4

Table 2. Per capital GDP in each city from 2017 to 2020

Unit: CNY/day · person^{-1}

city	2017	2018	2019	2020	city	2017	2018	2019	2020
Beijing	373.07	413.59	443.22	450.52	Jinan	269.25	291.24	291.55	302.41
Tianjin	239.12	262.16	278.24	277.63	Zibo	278.27	295.12	212.36	213.36
Shijiazhuang	162.70	134.47	144.82	141.84	Jining	151.86	161.57	143.37	146.90
Tangshan	205.98	218.03	237.44	255.38	Dezhou	148.55	159.59	143.27	149.43
Langfang	168.71	177.82	179.48	166.64	Liaocheng	136.45	142.29	101.72	106.29
Baoding	84.63	89.89	87.28	99.17	Binzhou	182.65	184.67	171.61	174.63
Cangzhou	138.42	133.05	130.58	138.56	Heze	89.20	96.39	106.48	108.52
Hengshui	95.29	95.61	92.05	100.92	Zhengzhou	256.96	292.08	260.12	262.66
Xingtai	83.34	80.03	78.65	84.45	Kaifeng	113.71	129.73	131.32	134.33
Handan	105.61	99.34	100.12	105.53	Anyang	120.13	113.90	111.25	115.26
Taiyuan	212.43	241.84	247.73	215.12	Hebi	140.19	155.39	171.30	171.41
Yangquan	130.93	142.40	138.87	153.67	Xinxiang	112.22	126.60	127.59	131.77
Changzhi	117.50	130.25	129.37	146.93	Jiaozuo	175.82	191.71	204.69	164.98
Jincheng	135.58	158.41	158.12	177.47	Puyang	119.56	109.06	115.47	119.97

Table 3. Per capita disposable income in each city from 2017 to 2020

Unit: CNY/ person

city	2017	2018	2019	2020	city	2017	2018	2019	2020
Beijing	57229	62361	67756	69434	Jinan	37787	41157	41472	43056
Tianjin	37022	39506	42404	43854	Zibo	32731	35434	37543	38932
Shijiazhuang	24651	26839	29335	30954	Jining	24883	27084	28054	29260
Tangshan	27785	30308	33080	34871	Dezhou	19641	21404	22608	23625
Langfang	27338	29781	32603	34357	Liaocheng	18866	20628	21601	22487
Baoding	19641	21708	23769	25204	Binzhou	25467.	27006	28516	29717
Cangzhou	21349	23271	25421	26887	Heze	17817	19545	20672	21740
Hengshui	18004	19869	22067	23527	Zhengzhou	30556	33105	35941	37274
Xingtai	18050	20052	22338	23772	Kaifeng	18282	19984	21794	22647
Handan	21167	23117	25371	26918	Anyang	21096	22825	24647	25530
Taiyuan	22039	23855	25897	27475	Hebi	22262	24093	26105	27110
Yangquan	28935	31031	33563	35473	Xinxiang	20855	22595	24561	25496
Changzhi	23422	25134	27126	28529	Jiaozuo	22953	24890	27115	28126
Jincheng	20551	22307	24313	25795	Puyang	18197	19801	21592	22583

As can be seen from Table 1, Beijing has the largest permanent resident population, which is above 20 million from 2017 to 2020 and slightly decreases year by year, followed by Tianjin, Shijiazhuang, Baoding and Zhengzhou, which has a permanent resident population between 10 million and 15 million. In addition, in Hebei, Hengshui has a population of less than 5 million, while other cities have populations between 5 million and 10 million. The population of the four cities in Shanxi is relatively small. Taiyuan has a population of about 5 million, while the other cities have a population of less than 5 million. The population of all cities in Shandong is between 5 million and 10 million except Zibo and Binzhou. Kaifeng, Hebi, Jiaozuo and Puyang in Henan have populations of less than five million, while Anyang and Xinxiang have populations of between five and seven million. Among them, the permanent population of Baoding showed an obvious trend of decline, while the population of Jinan and Zhengzhou showed an obvious trend of increase, and the change of the permanent population of other cities was small.

According to the per capita GDP of each city, Beijing's per capita GDP is the highest at 350 to 450 yuan, followed by Tianjin, Tangshan, Taiyuan, Jinan, Zibo and Zhengzhou with 200 to 300 yuan. Most other cities have daily GDP per capita of 100-200 yuan, while Baoding, Hengshui, Xingtai, Handan and Heze have daily GDP per capita of around 100 yuan. On the whole, the daily per capita GDP of each city showed a trend of growth. Table 3 shows that from 2017 to 2020, the per capita disposable income is similar to the per capita GDP, showing an increasing trend on the whole.

2.2.2. Exposure-response coefficients and benchmark rates

Due to the differences in the concentration of environmental pollutants at home and abroad, the impacts of $PM_{2.5}$ on different regions and different populations are different. In order to improve the reliability of the haze health economic loss assessment and reduce its error, the exposure-response relationship coefficients and the corresponding health benchmark rates used are shown in Table 4, based on a large number of studies by scholars at home and abroad and existing research results.

Table 4. Response coefficients for $PM_{2.5}$ exposure and baseline incidence at health endpoints

disease	Healthy Herminal	β	95%confidence interval		Baseline incidence
Death	early demise	0.296	0.076	0.504	
Hospital	respiratory system	0.109	0.000	0.221	0.0133
	cardiovascular system	0.068	0.043	0.093	0.0069
	asthma	0.210	0.145	0.274	0.0094
Sick	acute bronchitis	0.790	0.270	1.300	0.0372
	chronic bronchitis	1.009	0.366	1.559	0.0069
outpatient	pediatric	0.056	0.020	0.090	

From the baseline incidence of pediatrics and internal medicine, the baseline incidence of pediatrics in all provinces and cities showed a downward trend from 2017 to 2020. Compared with the baseline incidence in 2017, Shandong had the largest decline in the baseline incidence rate of pediatrics, from 10.33% to 8.69%, with a reduction of 1.64%. Beijing had a reduction of 0.83 percentage points, Tianjin had a reduction of 0.51%, and Hebei had a reduction of 0.81%. Shanxi Province increased by 0.22%, and Henan Province decreased by 0.94%.

The baseline incidence of premature death was obtained from the statistical yearbooks of each municipality. Incidence rates for respiratory and cardiovascular diseases were obtained from the Fifth National Health Services Survey. Incidence rates for medical and surgical clinics were calculated from the number of outpatient clinics in each region as a proportion of the total number of outpatient clinics in the China Health Statistics Yearbook. The results are shown in Table 5. baseline rates for acute and chronic bronchitis and asthma are based on previous studies.

Table 5. Baseline rates in pediatrics and medicine

	disease	2017	2018	2019	2020
Beijing	Pediatrics	8.08%	7.51%	7.25%	7.25%
	Internal medicine	22.12%	22.36%	22.33%	22.33%
Tianjin	Pediatrics	31.73%	32.13%	31.22%	31.22%
	Internal medicine	5.90%	5.82%	6.39%	6.39%
Hebei	Pediatrics	9.74%	9.23%	8.93%	8.93%
	Internal medicine	22.42%	22.38%	22.72%	22.72%
Shanxi	Pediatrics	7.79%	8.07%	8.01%	8.01%
	Internal medicine	22.99%	22.82%	23.03%	23.03%
Shandong	Pediatrics	10.33%	9.59%	8.69%	8.69%
	Internal medicine	19.61%	19.85%	20.28%	20.28%
Henan	Pediatrics	10.39%	9.95%	9.45%	9.45%
	Internal medicine	22.28%	22.37%	22.21%	22.21%

The baseline incidence of internal medicine in all provinces showed an overall upward trend from 2017 to 2020. Compared with the baseline incidence of internal medicine in 2017, the baseline incidence of internal medicine increased by 0.21% in Beijing, 0.49% in Tianjin, 0.30% in Hebei, 0.04% in Shanxi, 0.67% in Shandong, and 0.07% in Henan.

2.2.3. Unit economic loss of each health endpoint

According to the economic loss caused by premature death in Beijing, the per capita disposable income of each city (Table 3), and the growth rates of the price index CPI and per capita GDP, the statistical life value of other air pollution transmission channel cities except Beijing was calculated by using equations (4) and (5), and the results are shown in Table 6. Table 6 shows that the unit economic loss caused by premature death in each city in 2017 showed an increasing trend year by year.

Table 6. The economic loss per unit of premature mortality in each city from 2017 to 2020

Unit: ten thousand CNY/ person

city	**2017**	**2018**	**2019**	**2020**	**city**	**2017**	**2018**	**2019**	**2020**
Beijing	316.15	339.21	361.82	370.19	Jinan	208.74	223.88	221.46	229.56

Tianjin	204.52	214.89	226.44	233.81	Zibo	180.82	192.74	200.48	207.57
Shijiazhuang	136.18	145.99	156.65	165.04	Jining	137.46	147.33	149.81	156.01
Tangshan	153.49	164.86	176.65	185.92	Dezhou	108.50	116.43	120.73	125.96
Langfang	151.02	161.99	174.10	183.18	Liaocheng	104.22	112.21	115.36	119.90
Baoding	108.50	118.08	126.93	134.38	Binzhou	140.69	146.90	152.28	158.44
Cangzhou	117.94	126.59	135.75	143.35	Heze	98.43	106.32	110.39	115.91
Hengshui	99.46	108.08	117.84	125.44	Zhengzhou	168.80	180.07	191.93	198.73
Xingtai	99.71	109.07	119.29	126.74	Kaifeng	101.00	108.71	116.39	120.75
Handan	116.93	125.74	135.48	143.52	Anyang	116.54	124.16	131.62	136.11
Taiyuan	121.75	129.76	138.29	146.49	Hebi	122.98	131.05	139.40	144.54
Yangquan	159.84	168.79	179.23	189.13	Xinxiang	115.21	122.91	131.16	135.94
Changzhi	129.39	136.72	144.85	152.10	Jiaozuo	126.80	135.39	144.80	149.96
Jincheng	113.53	121.34	129.84	137.53	Puyang	100.52	107.71	115.30	120.41

The average number of days per hospital or outpatient visit and medical costs for each city were obtained from the China Health Statistics Yearbook. Based on the availability of data for each city, relevant health data for each city were replaced by provincial data, except for Beijing and Tianjin. Data on daily GDP per capita were obtained from the statistical yearbooks of the respective cities. Therefore, the unit economic cost of each health terminal can be calculated based on the data and formulae for the average number of outpatient visits, hospital days and medical costs for each health terminal. The results of the data on the average number of outpatient visits, days in hospital and medical costs for each health terminal are shown in Tables 7 and 8.

Table 7. Average medical expenditure per visit at each health terminal

year	Average length of stay (day/time)			average hospitalization expenditures (CNY/time)			Average outpatient days (day/time)
	cardiovascular system	respiratory system	asthma	cardiovascular system	respiratory system	asthma	
2017	8.60	7.71	7.83	27552.50	7699.50	6461.79	0.50
2018	8.30	7.69	7.70	28889.20	7772.50	6473.41	0.50
2019	8.10	7.53	7.63	30381.30	8045.60	6790.48	0.50
2020	8.10	7.53	7.63	30381.30	8045.60	6790.48	0.50

Table 8. The average daily outpatient expenditure

Unit:CNY

year	Beijing	Tianjin	Hebei	Shanxi	Shandong	Henan
2017	505.0	315.5	230.6	244.4	249.4	186.8
2018	544.8	339.3	239.5	255.7	253.8	193.8
2019	561.4	362.3	256.5	271.3	270.6	212.0
2020	561.4	362.3	256.5	271.3	270.6	212.0

According to the average medical cost per visit at each health terminal (Table 7), the average length of stay per hospitalization for cardiovascular disease, respiratory disease and asthma decreased year by year from 2017 to 2020, while the average hospitalization cost increased year by year. The average daily outpatient expenditure per capita (Table 8) shows that the average daily outpatient expenditure of each province and city has increased year by year.

3. Results and Discussion

Based on the concentration data of $PM_{2.5}$, permanent population, economic data and health data of each city, the secondary standard limit of years average concentration of $PM_{2.5}$ in the National Ambient Air Quality Standard (GB3095-2012) was $35\mu g/m^3$ as the reference concentration. Poisson regression relative risk model was used to estimate the changes of environmental health effects in 2+26 cities. Then, combined with the unit economic value of health terminals in each city, the economic loss value of each health terminal and the total health economic effect were estimated.

3.1. Assessment results of end-point health effects in 2+26 cities

Firstly, based on the $PM_{2.5}$ concentration data, Poisson relative risk model can be used to estimate the health effect change of each terminal attributable to $PM_{2.5}$ in each city, and the results are shown in Figure 3.

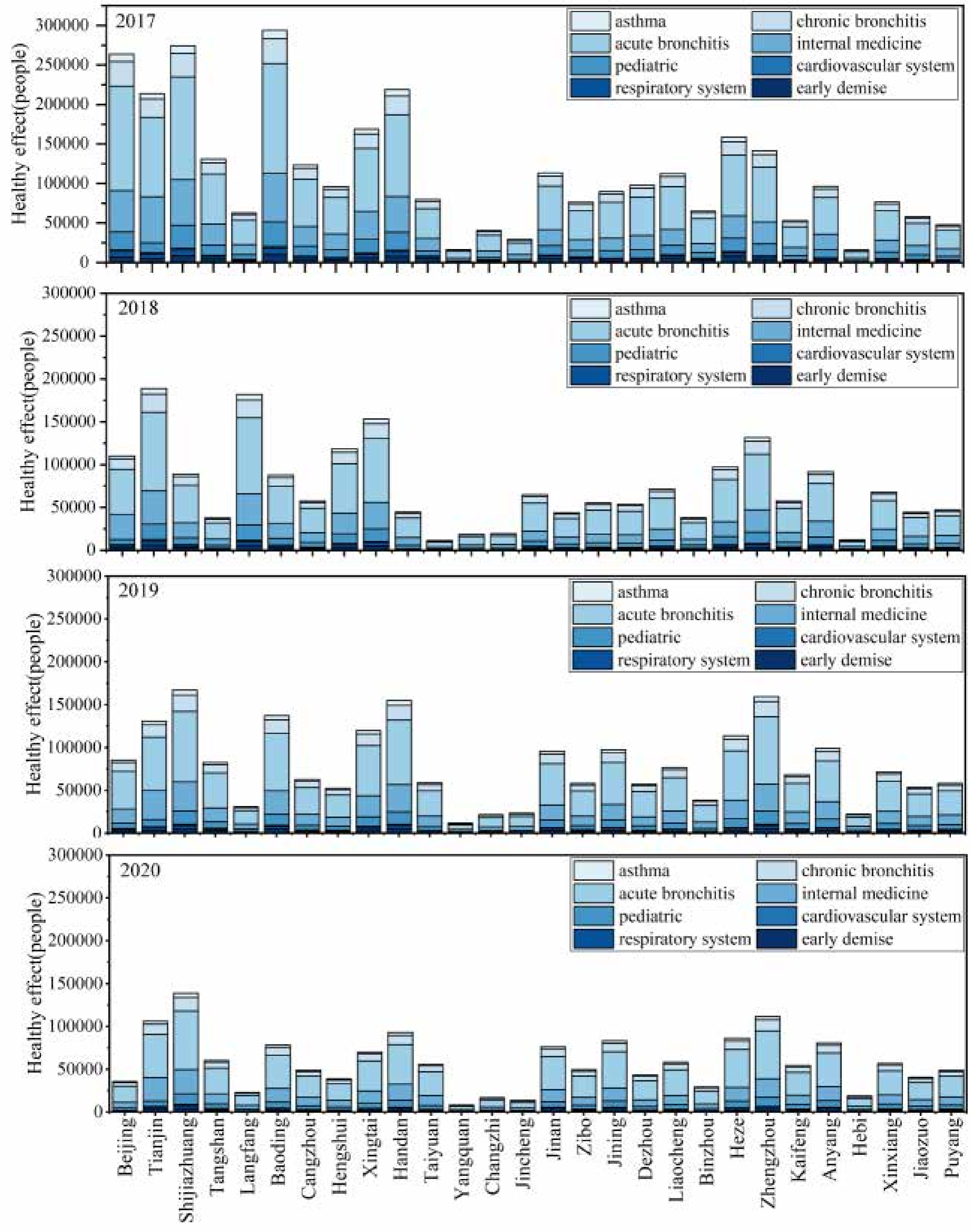

Fig. 3 Health endpoints attributable to $PM_{2.5}$ in each city from 2017 to 2020

In terms of the effect of $PM_{2.5}$ pollution on disease endpoints, the largest effect caused by $PM_{2.5}$ pollution was on patients, accounting for 61.03%-67.5% of the total health effect, followed by outpatient visits, accounting for 26.69%-33.09% of the total health effect. The proportion of people who die early is about 1%-7%, and the proportion of people who are hospitalized is relatively small, about 3%. Due to the different baseline incidence and exposure response coefficient of each disease endpoint, the health effects of $PM_{2.5}$ on disease endpoints were different.

Acute bronchitis accounted for 76% of the total population and 46.80%-51.71% of the total health effects, followed by asthma, accounting for 18% of the population and 10.69%-12.28% of the total health effects. Chronic bronchitis accounted for the least. Among the outpatients, the proportion of internal medicine patients was relatively large, accounting for about 62.44%-82.49% of the outpatients, accounting for 17.34%-27.29% of the total health effect, followed by the number of pediatric outpatients, accounting for about 5.79%-10.94% of the total health effect. Hospitalized patients with respiratory diseases accounted for 2.44%-2.74% of the total health effect, and hospitalized patients with cardiovascular diseases accounted for about 0.79%-0.90%.

In addition, the health effects of controlling $PM_{2.5}$ pollution in 2+26 cities from 2017 to 2020 for different health endpoints showed a decreasing trend year by year. The number of premature deaths in Beijing decreased from 7356 (95% CI: 1935, 12241) in 2017 to 863 (95% CI: 222, 1466) in 2020; the number of acute bronchitis cases in Tianjin decreased from 100195 (95% CI: 36657, 154465) in 2017 to (95% CI: 17791, 80205); the number of cardiovascular disease hospitalizations in Shijiazhuang decreased from 2460 (95% CI: 1565, 3344) to 1182 (95% CI: 750, 1612); the number of internal medicine outpatient visits in Taiyuan decreased from 16073 (95% CI: 8884, 22891) (95% CI: 6405, 16537); in Jinan, the number of asthma cases decreased from 4009 (95% CI: 2794, 5184) to 2709 (95% CI: 1879, 3517); in Zhengzhou, the number of pediatric outpatients decreased from 14809 (95% CI: 5310, 23712) to 10630 (95% CI: 1879, 3517). to 10630 cases (95% CI: 3807, 17037).

This phenomenon may be attributed to the significant decrease in $PM_{2.5}$ concentrations from 2017 to 2020 at certain baseline concentrations and the gradual decrease in baseline incidence of each disease, but in general, the decrease in $PM_{2.5}$ concentrations is the main reason for the decrease in the change in health impacts at each endpoint from 2017 to 2020. Therefore, taking the necessary measures to control and reduce $PM_{2.5}$ concentrations is an important means of reducing the health impacts of $PM_{2.5}$.

3.2. Assessment results of total health effects in 2+26 cities

By 2020, the top five cities with the highest total health effects attributable to $PM_{2.5}$ were Shijiazhuang, Zhengzhou, Tianjin, Handan and Heze, and the five cities with the lowest total health effects attributable to $PM_{2.5}$ were Yangquan, Jincheng, Changzhi, Hebian and Langfang. According to the distribution, the total health effect of the cities in Shanxi Province was low, and the total health effect of the cities in other provinces was distributed at different levels.

The total health effects attributed to $PM_{2.5}$ in each city from 2017 to 2020 are shown in Figure 4, which shows that the health effects of $PM_{2.5}$ are basically decreasing in all cities, except Kaifeng, Hebi and Puyang. In 2017, Beijing, Tianjin, and Hebei had a higher total health effect than Shandong, Henan, and Shanxi. In 2020, Beijing, Tianjin, and some cities in Hebei had a similar total health effect attributable to $PM_{2.5}$ and similar total health effect attributable to Shandong and Henan. This indicates that the effect of $PM_{2.5}$ control in the Beijing-Tianjin-Hebei region from 2017 to 2020 is relatively more significant. The average total health effect reduction of each city in Hebei province was second only to Beijing and Tianjin, followed by Shandong province, and Shanxi and Henan had the least reduction. Beijing, Baoding, Shijiazhuang, Handan and Tianjin were the top five cities where $PM_{2.5}$concentration reduced to $35\mu g/m^3$, and Hebei, Kaifeng, Puyang, Jining and Yangquan were the last five cities with more significant health effects.

The number of people affected by controlling $PM_{2.5}$ concentrations in Beijing to $35\mu g/m^3$ decreases from 263,733 cases (95% CI: 106,761, 402,704) to 148,116 cases (95% CI: 58944, 229,877) in 2018, from 855,518 cases (95% CI: 33716, 133,924) in 2019 to 35870 cases (95% CI: 14055, 56567) in 2020. The number of people affected by controlling $PM_{2.5}$ concentrations to $35\mu g/m^3$ in Baoding decreases from 294,030 cases (95% CI: 123,818, 433,126) to 182,064 cases (95% CI: 74,411, 275,437) in 2018 and from 137,293 cases (95% CI: 55618, 209,371) in 2019 decreasing to 78,499 cases in 2020 (95% CI: 31399, 121255). The number of people affected by controlling $PM_{2.5}$ concentrations to $35\mu g/m^3$ in Shijiazhuang decreases from 274,624 cases (95% CI: 115,885, 404,161) to 189,082 cases (95% CI: 777,08, 284,608) in 2018 and from 167,011 cases (95% CI: 68,353, 25,353) in 2019 down to 138,758 cases in 2020 (95% CI: 56,205, 2,11846). The number of people affected by controlling $PM_{2.5}$ concentrations to 35 in Hebe increases from 16,584 cases (95% CI: 7348, 24,782) to 12,395 cases (95% CI: 5480, 18,646) in 2018, to 22,182 cases (95% CI: 10031, 32687) in 2019, and to 18837 cases (95% CI: 8469, 27943). The number of people affected by controlling $PM_{2.5}$ concentrations to $35\mu g/m^3$ in Kaifeng increases from 53,590 cases (95% CI: 23,851, 7,905) to 57,794 cases (95% CI: 25,935, 85,792) in 2018, from 68,163 cases (95% CI: 30,911, 100,377) in

2019, to 54731 cases (95% CI: 24579, 81339). The number of people affected by controlling $PM_{2.5}$ concentrations to 35μg / m³ in Puyang decreased from 47,871 (95% CI: 21701, 70772) to 47,432 (95% CI: 21525, 70089) in 2018, from 58,178 (95% CI: 26670, 85138) in 2019, to 48,980 cases (95% CI: 22,381, 72,152).

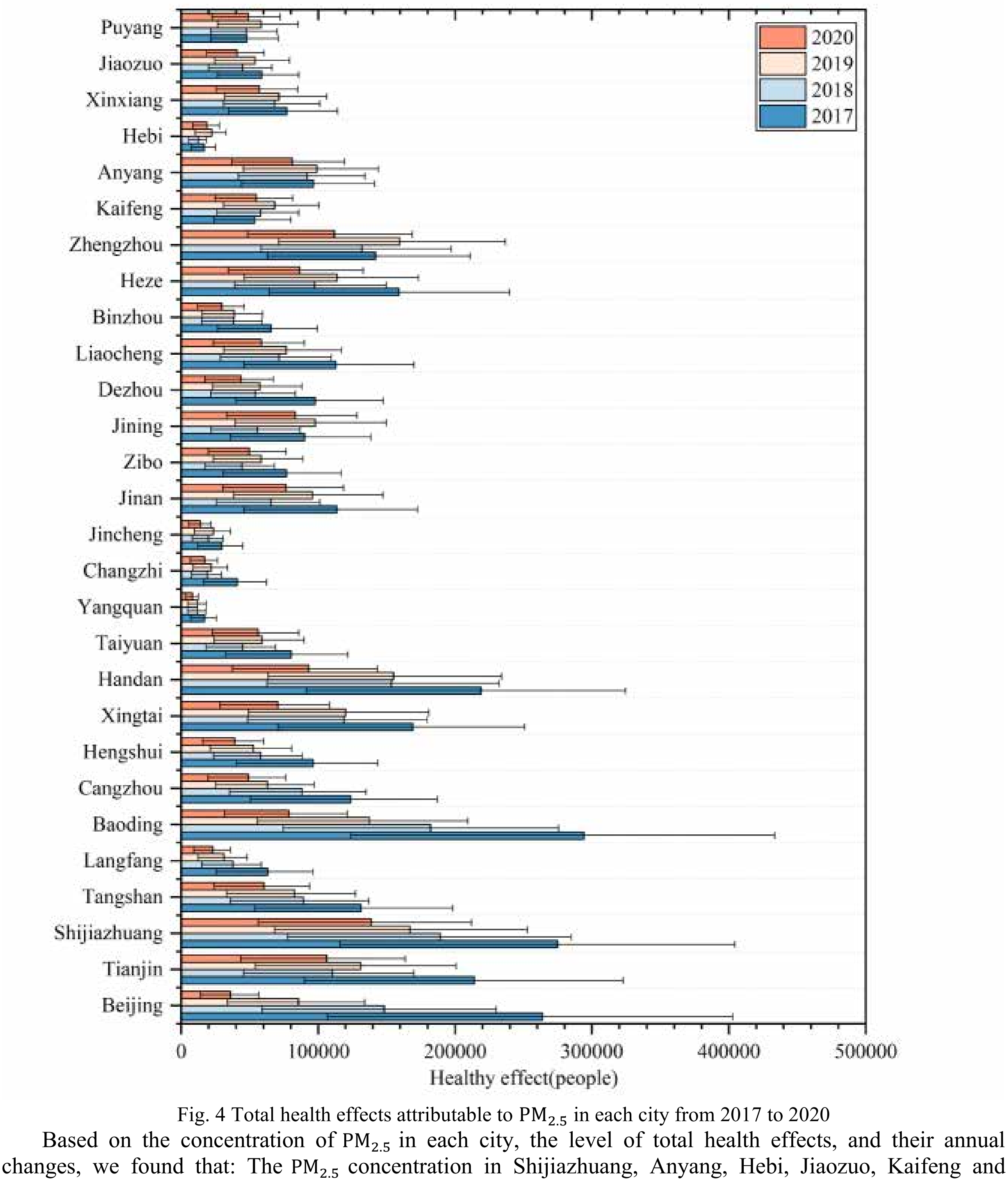

Fig. 4 Total health effects attributable to $PM_{2.5}$ in each city from 2017 to 2020

Based on the concentration of $PM_{2.5}$ in each city, the level of total health effects, and their annual changes, we found that: The $PM_{2.5}$ concentration in Shijiazhuang, Anyang, Hebi, Jiaozuo, Kaifeng and Puyang still has a large range of decline, because the average annual concentration of $PM_{2.5}$ in these cities in 2020 is above 55μg / m³, while Zhengzhou, Heze, Jining and Zibo have a large population base, and the $PM_{2.5}$ concentration is above 50μg / m³. Therefore, these cities have a greater potential for future health impacts if $PM_{2.5}$ concentrations are controlled.

3.3. Economic effects of each health endpoint in 2+26 cities

On the basis of the health effect assessment results, combined with the unit economic value of each health terminal in each city, the benefits of each health terminal brought by the control of $PM_{2.5}$ pollution from 2017 to 2020 in 2+26 cities were estimated. The estimated results are shown in Figure 5.

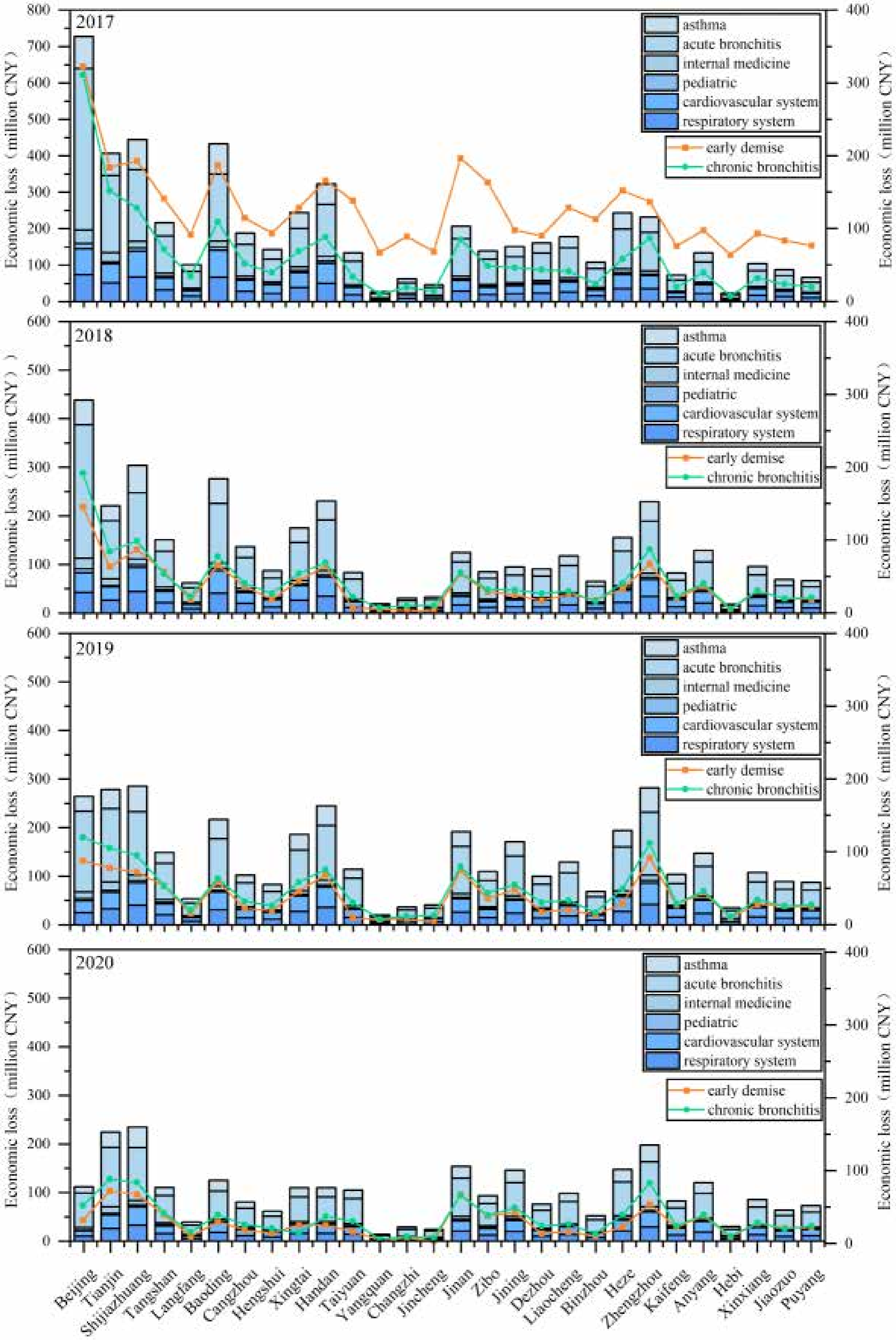

Fig. 5 The health economic effects attributable to $PM_{2.5}$ at each health endpoint in each city from 2017 to 2020

Premature death and chronic bronchitis accounted for more than 98% of the total economic loss. In 2020, the health economic loss due to premature death ranged from 28.66%-50.44%, and the health economic loss due to chronic bronchitis ranged from 48.04%-69.22% in 2+26 cities. The health economic loss caused by other health terminals accounted for less than 1%.

Looking at the changes in health economic losses by health endpoints in each city, the health economic effects of controlling $PM_{2.5}$ pollution in 2+26 cities from 2017 to 2020 for different health endpoints show a decreasing trend year by year. For example, the health economic loss due to premature death in Beijing decreases from 23.25 billion CNY (95% CI: 6.12, 38.70) in 2017 to 14.56 billion CNY (95% CI: 3.79, 24.48) in 2018 and from 8.76 billion CNY (95% CI: 2.27, 14.83) in 2019 to 3.20 billion CNY (95% CI: 0.82, 5.43) in 2020; the economic loss in health due to cardiovascular diseases in Tianjin decreased from 52.09 million CNY (95% CI: 33.04, 71.00) in 2017 to 27.26 million CNY (95% CI: 17.26, 37.21) and from 34.23 million CNY (95% CI: 21.72, 46.78) in 2019 to 27.48 million CNY (95% CI: 17.40, 37.52) in 2020; Shijiazhuang's economic loss of health due to internal medicine outpatient visits decreased from 18.05 million CNY (95% CI: 10.00, 25.65) to 11.82 million CNY (95% CI: 6.53, 16.82) in 2018 and from 11.30 million CNY (95% CI: 6.24, 16.09) in 2019 to 9.208 million CNY (95% CI: 5.08, 13.11); the economic loss of health due to paediatric outpatient clinics in Taiyuan decreased from 2.1803 million CNY (95% CI: 0.78, 3.49) in 2017 to 1.45 million CNY (95% CI: 0.50, 2.25) in 2018, from 1.94 million (95% CI: 0.70, 3.10) in 2019 to 1.74 million (95% CI: 0.63, 2.80) in 2020.

In addition, the economic loss in health due to acute bronchitis illness in Jinan decreased from 102.53 million (95% CI: 37.67, 157.43) in 2018 to 63.52 million CNY (95% CI: 22.61, 100.49) in 2018 and from 97.43 million CNY (95% CI: 35.04, 152.66) in 2019 to 79.39 million CNY (95% confidence interval. 28.07, 125.23); the economic loss in health due to chronic bronchitis illness in Zhengzhou decreased from 8.69 billion CNY (95% CI: 3.38, 12.67) in 2017 to 8.71 billion CNY (95% CI: 3.36, 12.77) in 2018, and from 11.19 billion CNY (95% CI: 4.37, 16.25) in 2019 to 8.30 billion CNY (95% CI: 3.17, 12.29) in 2020.

Because the health economic effects of $PM_{2.5}$ control are affected by factors such as $PM_{2.5}$ concentration, exposed population, baseline incidence of each health terminal, and economic value per unit, the health economic benefits of 2+26 cities will be different, even greatly different. For example, premature death and chronic respiratory diseases are estimated based on the value of statistical life (SVL) method. The loss caused by premature death is huge, and the health economic loss of chronic respiratory diseases due to its unit health is 32% based on Statistical life value results.

3.4. Total health economy effect in 2+26 cities

The total health economic effect attributed to $PM_{2.5}$ by city in 2020 is shown in Figure 6. According to Figure 6, in 2020, the high health economic effect was mainly distributed in some cities in Hebei, Shandong and Henan, and the health economic effect of other cities was basically within 10 billion yuan, among which the total health economy of cities in Shanxi Province was the lowest.

In 2020, the top 5 cities with the highest total health economic effect attributed to $PM_{2.5}$ are Tianjin, Shijiazhuang, Zhengzhou, Jinan, and Jining, and the bottom 5 cities are Yangquan, Jincheng, Changzhi, Hebi, and Binzhou. The total health economic benefits of controlling $PM_{2.5}$ pollution in 2020 are 16.32 billion CNY in Tianjin (95% CI: 5.32, 25.73), 15.41 billion CNY in Shijiazhuang (95% CI: 5.15, 23.86), and 13.93 billion CNY in Zhengzhou (95% CI: 4.67, 21.69), Jinan City's total health economic benefits were 13.58 billion CNY (95% CI: 4.36, 21.46), Jining City's total health economic benefits were 9.33 billion CNY (95% CI: 3.07, 14.60); Yangquan City's total health in Yangquan was 1.12 billion CNY (95% CI: 0.36, 1.78), total health economic benefits in Jincheng was 1.17 billion CNY (95% CI:0.40, 1.81), total health economic benefits in Changzhi was 1.83 billion CNY (95% CI: 0.59, 2.90), and total health economic benefits in Hebi was 1.93 billion CNY (95% CI: 0.64, 3.00), and Binzhou City had a total health economic benefit of 2.48 billion CNY (95% CI: 0.82, 3.90).

The top five cities with the highest total health economic effects attributable to $PM_{2.5}$ as a proportion of urban GDP were Anyang, Xingtai, Puyang, Shijiazhuang, and Handan, while the bottom five cities were Beijing, Zibo, Liaocheng, Dezhou, and Binzhou according to Figure 7. The total health economic benefits of controlling $PM_{2.5}$ pollution in 2020 are 3.45% of total GDP in Anyang (95% CI: 1.15%, 5.34%), 2.90% in Xingtai (95% CI: 0.98%, 4.51%), and 2.87% in Puyang (95% CI: 0.87%). 95% CI: 0.98%, 4.46%), Shijiazhuang 2.60% (95% CI: 0.87%, 4.02%) and Handan 2.36% (95% CI: 0.79%, 3.67%); the total health economic benefits from controlling $PM_{2.5}$ pollution in Beijing of total GDP was 0.24% (95% CI: 0.08%, 0.38%) in Beijing, 0.20% (95% CI: 0.06%, 0.31%) in Zibo, 0.19% (95% CI: 0.07%, 0.30%) in Liaocheng, and 0.17% (95% CI: 0.07%, 0.30%) in Dezhou. economic benefits of 0.17% (95% CI: 0.06%, 0.26%) and Binzhou City's total health economic benefits of 0.08% (95% CI: 0.03%, 0.13%).

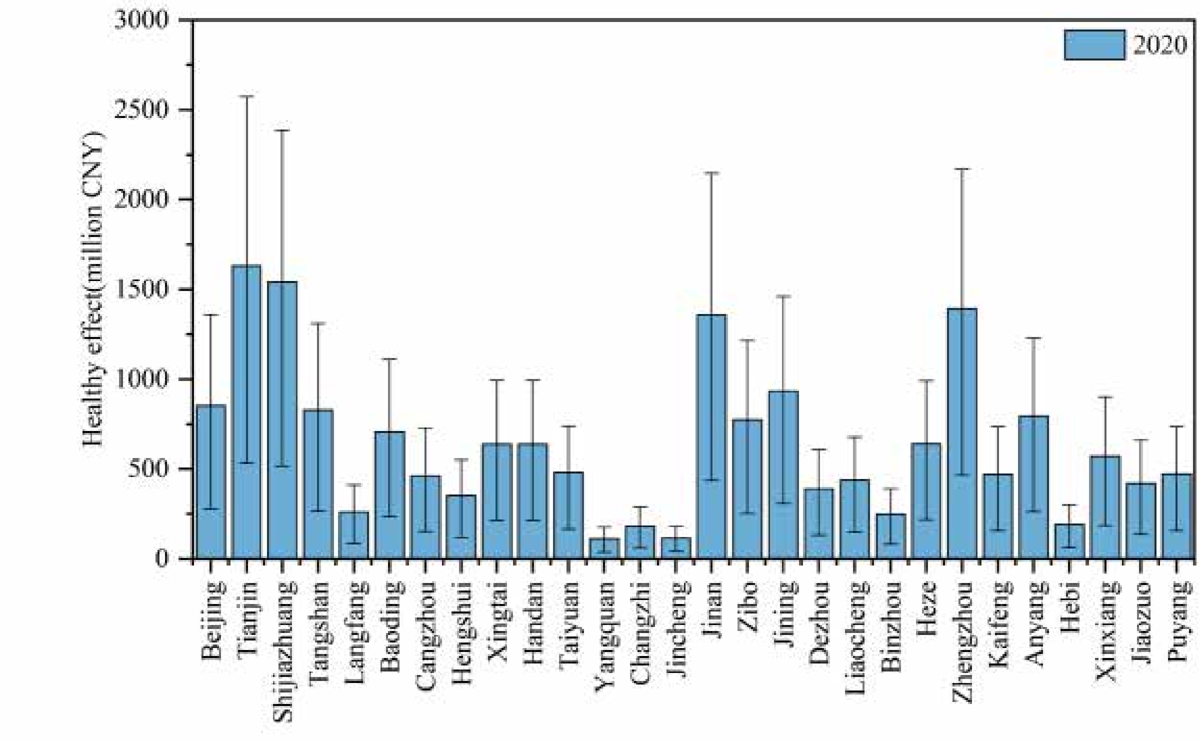

Fig. 6 The health economic effects of each health terminal attributable to $PM_{2.5}$ in each city in 2020

From 2017 to 2020, the total health economic effects attributable to $PM_{2.5}$ decreased in all cities, but there were some cities with increasing health economic effects. Beijing, Baoding, Handan, Tianjin and Shijiazhuang showed the most significant decline in health economic effects, while Anyang, Hebei, Puyang, Jining and Kaifeng showed an increase in health economic effects. Table 9 shows the total health-economic effects attributable to $PM_{2.5}$ for each city from 2017 to 2020

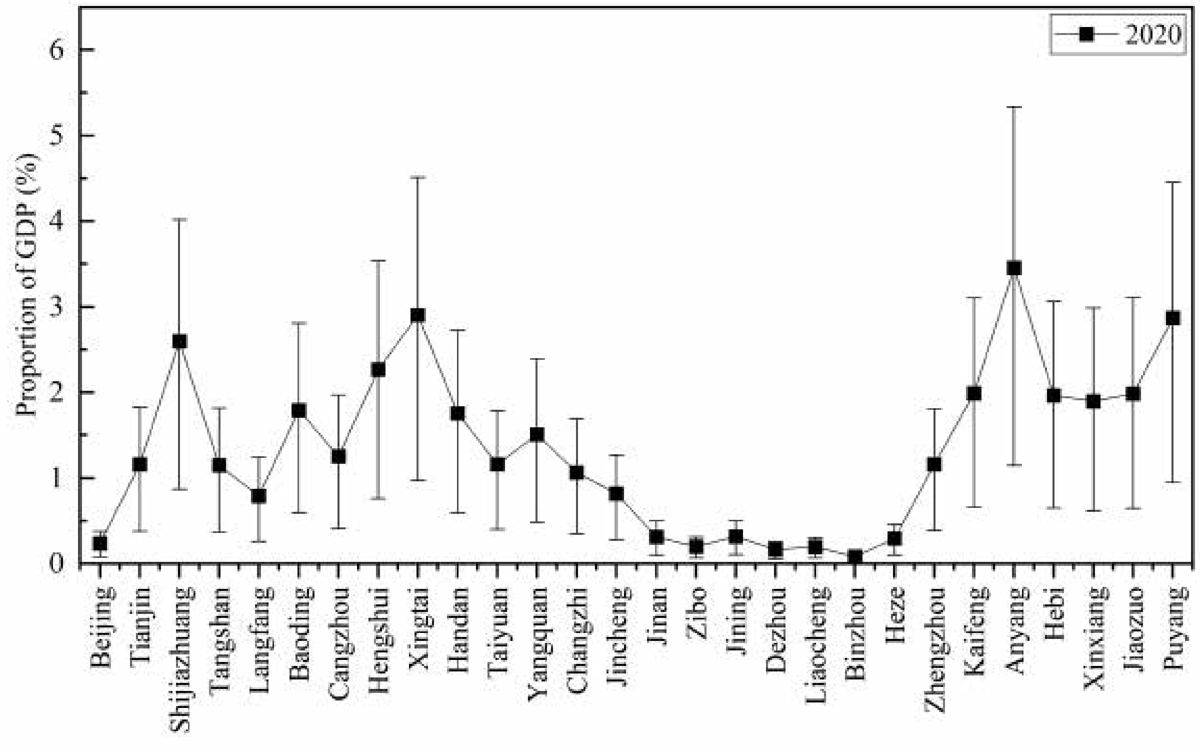

Fig. 7 The proportion of total health economic effects attributable to $PM_{2.5}$ in GDP in each city from 2017 to 2020

The total health economic benefits from controlling $PM_{2.5}$ pollution in Beijing decreased from CNY 55.07 billion (95% CI: 18.50, 85.13) in 2017 to CNY 8.53 billion (95% CI: 2.78, 13.61) in 2020; the total health economic benefits from controlling $PM_{2.5}$ pollution in Baoding decreased from CNY 22.70 billion CNY (95% CI: 7.85, 34.01) in 2017 to 7.08 billion CNY (95% CI: 2.34, 11.10) in 2020; the total health economic benefits of controlling $PM_{2.5}$ pollution in Tianjin from 26.72 billion CNY (95% CI: 9.10, 40.97) in 2017 decreasing to CNY 16.32 billion in 2020 (95% CI: 5.32, 25.73); the total health economic benefits of controlling $PM_{2.5}$ pollution in Handan decreasing from CNY 18.69 billion in 2017 (95% CI: 6.39, 28.26) to CNY 8.59 billion in 2020 (95% CI: 2.88, 13.35); the total health economic benefits of controlling $PM_{2.5}$ pollution in Shijiazhuang decreased from CNY 25.16 billion (95% CI: 8.81, 37.50) in 2017 to CNY 15.41 billion (95% CI: 5.15, 23.87) in 2020.

Among the cities with increasing health economic effects, the total health economic benefits from $PM_{2.5}$ pollution control in Anyang city increased from 7.66 billion CNY (95% CI: 2.60, 11.69) in 2017 to 7.94 billion CNY (95% CI: 2.64, 12.28) in 2020. The total health economic benefits from the control of $PM_{2.5}$ pollution in Hebi increased from 1.37 billion CNY (95% CI: 0.45, 2.13) in 2017 to 1.93 billion CNY (95% CI: 0.64, 3.00) in 2020. The total health economic benefits caused by $PM_{2.5}$ pollution control in Puyang increased from 3.78 billion CNY (95% CI: 1.26, 5.87) in 2017 to 4.73 billion CNY (95% CI: 1.56, 7.35) in 2020. The total health economic benefits from $PM_{2.5}$ pollution control in Jining increased from 8.34 billion CNY (95% CI: 2.79,12.97) in 2017 to 9.33 billion CNY (95% CI: 3.07,14.60) in 2020. The total health economic benefits of $PM_{2.5}$ pollution control in Kaifeng increased from 3.71 billion CNY (95% CI: 1.23, 5.77) in 2017 to 4.72 billion CNY (95% CI: 1.55, 7.36) in 2020.

Table 9. Total health economic effects attributable to $PM_{2.5}$ in each city from 2017 to 2020

Unit: billion CNY

city	2017	2018	2019	2020
Beijing	55.07(18.50,85.13)	34.20(11.20,53.87)	21.04(6.83,33.45)	8.53(2.78,13.61)
Tianjin	26.72(9.10,40.94)	15.02(4.95,23.60)	18.62(6.18,29.09)	16.32(5.32,25.73)
Shijiazhuang	25.16(8.81,37.50)	18.91(6.41,28.9)	17.01(5.80,26.04)	15.41(5.15,23.87)
Tangshan	14.73(4.90,22.70)	11.23(3.64,17.6.2)	10.86(3.53,17.05)	8.28(2.67,13.10)
Langfang	6.59(2.19,10.21)	4.18(1.37,6.58)	3.64(1.19,5.75)	2.61(0.86,4.11)
Baoding	22.70(7.85,34.01)	14.60(4.94,22.41)	12.50(4.14,19.43)	7.08(2.34,11.10)
Cangzhou	10.44(3.49,16.06)	7.94(2.62,12.38)	5.52(1.84,8.63)	4.63(1.53,7.29)
Hengshui	7.31(2.55,10.98)	4.61(1.57,7.09)	4.63(1.56,7.17)	3.54(1.19,5.51)
Xingtai	13.38(4.64,20.09)	10.01(3.40,15.31)	10.63(3.63,16.24)	6.39(2.15,9.93)
Handan	18.69(6.37,28.25)	13.64(4.56,20.97)	14.68(4.94,22.54)	8.59(2.88,13.33)
Taiyuan	10.64(3.29,16.83)	2.98(1.06,4.55)	4.14(1.49,6.25)	4.82(1.66,7.41)
Yangquan	1.89(0.63,2.9)	1.28(0.43,1.99)	1.54(0.50,2.43)	1.12(0.36,1.78)
Changzhi	4.79(1.51,7.57)	1.39(0.48,2.16)	2.04(0.68,3.20)	1.83(0.59,2.90)
Jincheng	2.46(0.84,3.78)	1.32(0.48,2.00)	1.66(0.60,2.51)	1.17(0.40,1.81)
Jinan	20.94(6.69,32.74)	10.99(3.55,17.33)	15.65(5.12,24.47)	13.58(4.36,21.47)
Zibo	14.35(4.48,22.61)	6.21(2.03,9.76)	8.07(2.70,12.50)	7.75(2.53,12.14)
Jining	8.35(2.79,12.97)	5.73(1.87,9.04)	10.51(3.48,16.35)	9.33(3.07,14.60)
Dezhou	7.46(2.60,11.29)	4.47(1.51,6.93)	4.95(1.68,7.65)	3.91(1.32,6.09)
Liaocheng	10.59(3.42,16.44)	5.70(1.89,8.87)	5.51(1.90,8.45)	4.39(1.49,6.78)
Binzhou	7.43(2.32,11.71)	3.48(1.12,5.48)	3.11(1.03,4.86)	2.48(0.82,3.90)
Heze	14.43(4.68,22.37)	7.60(2.53,11.82)	8.04(2.78,12.28)	6.40(2.189.9.90)
Zhengzhou	15.90(5.31,24.64)	15.67(5.22,24.36)	20.61(6.90,31.88)	13.93(4.67,21.69)
Kaifeng	3.71(1.23,5.77)	4.41(1.46,6.86)	5.68(1.89,8.80)	4.72(1.55,7.36)
Anyang	7.66(2.60,11.69)	7.88(2.66,12.07)	9.22(3.11,14.08)	7.94(2.64,12.28)
Hebi	1.37(0.46,2.13)	1.12(0.37,1.77)	2.18(0.73,3.37)	1.93(0.64,3.00)
Xinxiang	6.49(2.13,10.13)	6.15(2.01,9.64)	6.36(2.12,9.89)	5.72(1.85,9.01)
Jiaozuo	4.81(1.61,7.39)	4.06(1.33,6.32)	5.23(1.73,8.09)	4.21(1.37,6.60)
Puyang	3.78(1.26,5.8.7)	4.01(1.33,6.23)	5.29(1.78,8.14)	4.74(1.57,7.36)

According to the health economic effects attributed to $PM_{2.5}$ in each city, we found that: The health economic benefits of $PM_{2.5}$ control in Beijing-Tianjin-Hebei region were higher than those in other regions.

Beijing had the most significant health economy effect, while some cities in Shandong and Henan had less health economy effect from $PM_{2.5}$ control, but the health economic effect also increased.

Table 10 shows the proportion of total health economic effects attributable to $PM_{2.5}$ in GDP of each city from 2017 to 2020. The proportion of the total health economic effects attributable to $PM_{2.5}$ in GDP in each city showed an overall downward trend from 2017 to 2020, but there were also some cities with an increase in the health economic effects. The proportion of total health economic effects in each city ranged from 1.66%-7.25% in 2017, and from 0.08%-3.45% in 2020. The top five cities with the most significant decline in the proportion of health economic effects were Baoding, Heze, Liaocheng, Xingtai and Handan, and the cities with the most significant increase in the proportion of health economic effects were Puyang, Hebei, Anyang and Kaifeng.

Table 10. The proportion of total health economic effects attributable to $PM_{2.5}$ in GDP in each city from 2017 to 2020

Unit: %

city	2017	2018	2019	2020
Beijing	1.84(0.62,2.85)	1.03(0.34,1.63)	0.59(0.19,0.94)	0.24(0.08,0.38)
Tianjin	2.15(0.73,3.29)	1.12(0.37,1.77)	1.32(0.44,2.07)	1.16(0.38,1.83)
Shijiazhuang	4.40(1.54,6.55)	3.78(1.28,5.77)	2.93(1.00,4.48)	2.60(0.87,4.02)
Tangshan	2.26(0.75,3.48)	1.78(0.58,2.80)	1.58(0.51,2.47)	1.15(0.37,1.82)
Langfang	2.29(0.76,3.54)	1.38(0.45,2.17)	1.14(0.37,1.80)	0.79(0.26,1.25)
Baoding	7.25(2.51,10.86)	4.53(1.53,6.95)	3.31(1.10,5.15)	1.79(0.59,2.81)
Cangzhou	2.86(0.96,4.41)	2.43(0.80,3.79)	1.54(0.51,2.41)	1.25(0.41,1.97)
Hengshui	4.80(1.68,7.21)	3.34(1.14,5.13)	3.08(1.03,4.76)	2.27(0.76,3.53)
Xingtai	6.40(2.22,9.61)	5.14(1.75,7.86)	5.02(1.71,7.66)	2.90(0.98,4.51)
Handan	5.53(1.88,8.36)	4.19(1.40,6.43)	4.21(1.42,6.47)	2.36(0.79,3.67)
Taiyuan	3.15(0.97,4.98)	0.77(0.27,1.17)	1.03(0.37,1.56)	1.16(0.40,1.78)
Yangquan	2.82(0.94,4.37)	1.74(0.58,2.72)	2.15(0.70,3.38)	1.51(0.48,2.39)
Changzhi	3.24(1.02,5.12)	0.84(0.29,1.31)	1.24(0.41,1.95)	1.07(0.34,1.69)
Jincheng	2.14(0.73,3.28)	0.98(0.35,1.48)	1.23(0.44,1.85)	0.82(0.28,1.27)
Jinan	3.18(1.02,4.97)	1.54(0.50,2.42)	1.66(0.54,2.59)	0.32(0.10,0.50)
Zibo	3.21(1.00,5.05)	1.30(0.42,2.04)	2.22(0.74,3.43)	0.20(0.06,0.31)
Jining	1.91(0.67,2.98)	1.24(0.40,1.95)	2.40(0.56,2.53)	0.32(0.10,0.50)
Dezhou	2.50(0.87,3.79)	1.42(0.48,2.21)	1.64(0.84,3.74)	0.17(0.06,0.31)
Liaocheng	3.70(1.19,5.74)	1.89(0.63,2.94)	2.44(0.42,1.98)	0.19(0.07,0.30)
Binzhou	2.96(0.92,4.66)	1.34(0.43,2.11)	1.27(0.82,3.60)	0.08(0.03,0.13)
Heze	5.57(1.81,8.64)	2.69(0.90,4.18)	2.36(0.60,2.75)	0.29(0.10,0.46)
Zhengzhou	1.73(0.58,2.68)	1.47(0.49,2.28)	1.78(0.82,3.82)	1.16(0.39,1.81)
Kaifeng	1.96(0.65,3.06)	2.04(0.68,3.18)	2.47(0.60,2.75)	1.99(0.65,3.10)
Anyang	3.41(1.16,5.20)	3.68(1.24,5.63)	4.20(0.82,3.83)	3.45(1.15,5.34)
Hebi	1.66(0.55,2.58)	1.22(0.40,1.92)	2.25(1.42,6.42)	1.97(0.65,3.06)
Xinxiang	2.75(0.90,4.30)	2.30(0.75,3.61)	2.19(0.75,3.41)	1.90(0.61,2.99)
Jiaozuo	2.11(0.71,3.24)	1.62(0.53,2.53)	2.00(0.75,3.41)	1.98(0.64,3.11)
Puyang	2.39(0.79,3.70)	2.78(0.92,4.32)	3.35(1.13,5.16)	2.87(0.95,4.46)

The proportion of total health economic benefits in GDP from $PM_{2.5}$ pollution control in Baoding decreased from 7.25% (95% CI: 2.51%, 10.86%) in 2017 to 0.59% (95% CI: 2.81%, 5.46%), decreased by 5.46 percentage points (95% CI: 1.91%, 8.05%); The proportion of total health economic benefits in Heze decreased from 5.57% (95% CI: 1.81%, 8.64%) in 2017 to 0.29% (95% CI: 0.10%, 0.46%) in 2020, with a decrease of 5.28 percentage points (95% CI: 1.71%, 8.19%). The proportion of total health economic benefits in Liaocheng decreased from 3.70% (95% CI: 1.19%, 5.74%) in 2017 to 0.19% (95% CI: 0.07%, 0.30%) in 2020, with a decrease of 3.50 percentage points (95% CI: 1.13%, 5.43%). The proportion of total health economic benefits in Xingtai decreased from 6.40% (95% CI: 2.22%, 9.61%) in 2017 to 2.90% (95% CI: 0.98%, 4.51%) in 2020, with a decline of 3.50 percentage points (95% CI: 1.25%, 5.10%). The proportion of total health economic benefits in Handan decreased by 3.17 percentage points (95% CI: 1.09%, 4.69%) from 5.53% (95% CI: 1.88%, 8.36%) in 2017 to 2.36% (95% CI: 0.79%, 3.67%) in 2020.

Among the cities with an increase in the proportion of total health economic effects, the proportion of total health economic benefits in GDP caused by $PM_{2.5}$ pollution control in Puyang increased from 2.39% (95% CI: 0.79%, 3.70%) in 2017 to 2.87% (95% CI: 3.70%) in 2020. 0.95%, 4.46%), an increase of 0.48 percentage points (95% CI: 0.16%, 0.75%); The proportion of total health economic benefits in GDP in Hebi increased from 1.66% (95% CI: 0.55%, 2.58%) in 2017 to 1.97% (95% CI: 0.65%, 3.06%) in 2020, with an increase of 0.31 percentage points (95% CI: 0.55%, 2.58%). 0.10%, 0.48%); The proportion of total health economic benefits in GDP of Anyang increased from 3.41% (95% CI: 1.16%, 5.20%) in 2017 to 3.45% (95% CI: 1.15%, 5.34%) in 2020, an increase of 0.05 percentage points (95% CI: 1.16%, 5.20%). -0.01%, 0.14%); The proportion of Kaifeng's total health economic benefits in GDP increased from 1.96% (95% CI: 0.65%, 3.06%) in 2017 to 1.99% (95% CI: 0.65%, 3.10%) in 2020, an increase of 0.03 percentage points (95% CI: 0.65%, 3.10%). 0.00%, 0.04%).

According to the proportion of health economic effects attributable to $PM_{2.5}$ in each city, we can see that: In 2017, cities with a higher proportion of health benefits had a greater reduction in the proportion of health economic benefits caused by $PM_{2.5}$ control than other regions. Among them, Hebei and Shandong provinces had a more significant change in the proportion of health economic effects caused by $PM_{2.5}$ control, while some cities in Henan Province had less health economic effects caused by $PM_{2.5}$ control. There was also an increase in the proportion of health economic effects in these cities, which had a smaller base in 2017 and therefore showed a smaller increase. The proportion of total health benefits showed an overall downward trend, and the proportion range gap narrowed from 1.66%-7.25% in 2017 to 0.08%-3.45% in 2020, indicating that after a series of measures were taken to control $PM_{2.5}$ pollution, The gap of the proportion of health economic loss attributable to $PM_{2.5}$ in each city was gradually narrowing, which reflected that regional comprehensive measures were helpful to encourage urban pollution control.

4. Conclusion

Based on the annual average $PM_{2.5}$ concentration data, economic data and health data from 2017 to 2020 in 2+26 cities, we used exposure-response model combined with Poisson regression relative risk model to estimate the health effects attributable to $PM_{2.5}$ pollution for eight health end points (premature death, outpatient visit, hospitalization and illness). The statistical life value method and the cost of disease method were used to evaluate the health economic effects attributable to $PM_{2.5}$, and the following conclusions were finally drawn.

In general, the average annual $PM_{2.5}$ concentration in 2+26 cities showed a gradual downward trend from 2017 to 2020, with the average annual $PM_{2.5}$ concentration decreasing from 65.07μg / m^3 to 51.25μg / m^3. In each city, the maximum value of annual $PM_{2.5}$ decreased from 84.00μg / m^3 to 62.25μg / m^3, and the minimum value decreased from 54.42μg / m^3 to 37.92μg / m^3. This indicates that some achievements have been made in the management of $PM_{2.5}$ concentration in 2+26 cities, but it can be seen that the $PM_{2.5}$ concentration in 2+26 cities is still far from the secondary limit of 35 in the Air Environmental Quality Standard. The analysis also found that some cities in Shanxi, Shandong and Henan saw an increase in $PM_{2.5}$ concentration between 2018 and 2019.

From the perspective of health effect attributed to $PM_{2.5}$, the greatest impact of $PM_{2.5}$ was on diseases, accounting for 61.03%-67.5% of the total health effect, followed by outpatient visits, accounting for 26.69%-33.09% of the total health effect. The proportion of people who die early is about 1%-7%, and the proportion of people who are hospitalized is relatively small, about 3%. Specific to each health endpoint, the number of people affected from high to low was acute bronchitis, medical clinic, chronic bronchitis, asthma, respiratory disease, premature death, and cardiovascular disease. In addition, the health effects attributable to $PM_{2.5}$ at each disease end point and the total health effects in 2+26 cities showed a gradual downward trend from 2017 to 2020, and the health effects in 2020 were significantly lower than those in 2017. Overall, the decrease in $PM_{2.5}$ concentration was the main reason for the decrease in the change in health effects from 2017 to 2020 across all terminals in each city.

From the perspective of health economic effects attributable to $PM_{2.5}$ the order of health economic effects attributable to $PM_{2.5}$ from high to low was chronic bronchitis, early death, acute bronchitis, asthma, cardiovascular disease, respiratory disease, internal medicine, and pediatrics. Among them, premature death and chronic bronchitis accounted for 98% of the health economic effects. The reason for this situation is that the loss caused by premature death is huge, and the unit health economic loss of chronic respiratory diseases is 32% based on the results of statistical life value, so the health economic benefits of these two health terminals are relatively high. From 2017 to 2020, the individual health economic effects and the total health economic effects attributable to $PM_{2.5}$ declined in all cities, but there were some cities with increasing health economic effects.

Based on the above findings, the reduction of health effects and health economic effects attributed to $PM_{2.5}$ in 2+26 cities is mainly due to the reduction of $PM_{2.5}$ concentration. There is still room for further reduction of $PM_{2.5}$ pollution in each city. Therefore, in the future, Cities can still take corresponding measures to control $PM_{2.5}$ to reduce the health benefits and health economic benefits caused by $PM_{2.5}$. After a series of measures have been taken to control $PM_{2.5}$ pollution, the gap of the proportion of health economic loss attributable to $PM_{2.5}$ among cities has gradually decreased, which reflects that regional comprehensive measures are helpful to encourage urban pollution control to some extent. However, we also found that the reduction of health effects and health economic effects and the magnitude of reduction differed greatly among cities with different lvels of development. Therefore, for some cities with a low level of economic development, they are facing the pressure of economic development and the pressure of reducing pollution. How to achieve the effect of reducing haze pollution while developing the economy is the problem that these cities need to solve at present.

Based on previous studies, we evaluated the health effects and health economic effects attributable to $PM_{2.5}$ in 2+26 air pollution transmission channel cities from 2017 to 2020. Because only eight health endpoints of early death, outpatient service, hospitalization, and illness were considered, it may be possible to underestimate the impact of these health endpoints. Nevertheless, the study can provide certain reference for the future control of air pollution in cities with air pollution transmission channels.

Declarations

Ethics approval and consent to participate. Not applicable.

Consent for publication. Not applicable.

Competing interests. The authors declare no competing interests.

Acknowledgments. This work was supported by the Major Program of the National Social Science Fund of China (Grant No. 17ZDA092)

Author contribution. All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Lushuang Xiao. The first draft of the manuscript was written by Lushuang Xiao, and Lushuang Xiao and Guizhi Wang contributed to manuscript revision, read, and approved the submitted version.

Funding. National Social Science Fund of China (Grant No. 17ZDA092)

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