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# Assessment of China's Human Health Loss Caused by $PM_{2.5}$ in 2017 Based on Remote Sensing Inversion

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# Foreword »

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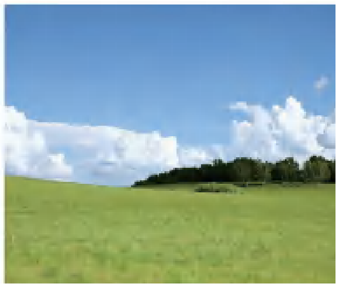


Since its opening-up and reform, China has been in the process of rapid economic development with its people enjoying an increasingly improved standard of life. Meanwhile accompanying this dramatic economic growth is the degradation of environment which has, to some extent, damaged the gains of the opening-up and reform and prevented the economy from a healthy and sustainable development. The Chinese government is increasingly aware of that without addressing the environmental issues it is facing now, will jeopardize its long term goal of the great rejuvenation of the Chinese nation. Given the magnitude and complexity of the environmental issues in China, there is no easy way in addressing them and the solution to them entails an equal priority being given to environmental protection, ecological conservation and economic development or even higher than the latter by mainstreaming the former into the overall socio-economic decision-making process. As a matter of fact, China has been in the struggle against environmental pollution since the very beginning of its economic take-off and trying to explore a pathway that could help address China's environmental issues in the way most suitable to China's specific circumstances.

In recent years, especially since the 12th Five-Year Plan period, the enhanced measures including legislation, policy, regulatory and economic means have been taken by the Chinese government in dealing with environmental problems, of which environmental policies have played an important role in this regard. Corresponding to this situation and in meeting the demand of governments at different levels for environmental policy tools, the environmental policy research projects on topics of a wide range have been conducted by some Chinese environmental research institutions including the Chinese Academy of Environmental Planning (CAEP).

CAEP founded in 2001, is a research advisory body supporting governments in the development of key environmental planning, national environmental policies, and major environmental engineering projects. In the past more than 10 years, CAEP has accomplished the development of the overall planning of national environmental protection for the 10th, 11th and 12th Five-Year Plan periods; water pollution prevention and control planning for key river basins; air pollution prevention and control planning for key regions; soil pollution prevention and control planning; and some regional environmental protection plans. In the same period of time, CAEP also actively engaged in research on such topics as green GDP, environmental taxation, emission trading, ecological compensation, green financing, etc. By so doing, CAEP has become an indispensable advisory body in the environmental decision-making in mainland China. According to *2013 Global Go To Think Tanks Report and Policy Advice* published by University of Pennsylvania, CAEP was ranked 31 in the field of environment in the world. Many of CAEP's research results and project outcomes regarding environmental policies have drawn great attention of decision makers and international institutions, and have been utilized to contribute to the formulation of national environmental policies concerned.

*The Chinese Environmental Policy Research Working Paper (CEPRWP)* is a new internal publication produced by CAEP for the purpose of facilitating the academic exchange with foreign colleagues in this field, in which the selected research papers on environmental policies from CAEP are set out on the irregular basis. It is expected that this publication will not only make CAEP's research results on environmental policies be known by foreign colleagues but also serve as a catalyst for creating opportunity of international cooperation in the field of environmental policies, and environmental economics in particular, with a view of both the academic research and practical policy needs.

With the frequent occurrence of smoggy weather in China, the loss of human health caused by the fine particles has attracted much public attention. In this paper, we have adopted the MODIS aerosol product MOD04-10KM data in 2017 and the $PM_{2.5}$ monitoring data of 338 cities above the prefecture/county level in China to invert the 10km×10km gridded $PM_{2.5}$ concentration data and use the Disability-Adjusted Life Year (DALY) index to conduct the gridded assessment of the economic burden of human health such as premature death, hospitalization and disability caused by $PM_{2.5}$ in China in year 2017, to analyze the spatial differences in human health loss caused by fine particulate matter in China. The following conclusions were drawn: 1) Approximately 75.4% of China's population is exposed to areas, where the $PM_{2.5}$ concentration is higher than National Standard Grade II; 2)

In 2017, the number of premature deaths caused by $PM_{2.5}$ nationwide was about 813,000 and the number of circulatory and respiratory inpatients was almost 1.999 million; 3) The human health loss caused by $PM_{2.5}$ in China is CNY 1042.84 billion, accounting for 1.23% of GDP. Among them, the premature death loss was CNY 895.08 billion, the hospitalization loss was CNY 19.97 billion, and the disability loss was CNY 127.79 billion which are accounting for 71.2%, 1.59%, and 10.2% of overall costs respectively[1].

[1] This study was supported by the National Key Research and Development Program of China (No. 2016YFC0208804).

# Contents

# 1. INTRODUCTION

As the smog often attacks China, the loss of human health caused by fine particles has become the focus of public attention. In 2010, these problems turn out to be the fourth major factor for the burden of disease in China (Yang et al., 2013). The burden of disease consists of two aspects, namely the epidemiological burden and economic burden. Currently, the burden of disease method is mainly used in health impact assessment of the air pollution on a regional scale (Yu et al, 2009; World Bank, 2011; Health Effects Institute, 2012; Ostro, 2004). Although, the environmental pollution does not cause direct death in most of the cases, it may affect the life quality of the patients. The World Bank and WHO have proposed the index of Disability-Adjusted Life Year (DALY) for assessing the burden of disease (Murray,1994). DALY refers to all the healthy years of life lost from onset of disease to death, including years of life lost due to both premature death and disability caused by disease. DALY comprehensively considers factors such as death, disease, disability, age weighting, time discounting etc., and objectively reflects the degree of threats caused by the disease to human society (Hu, 2005).

The World Bank, WHO and other international organizations have carried out health damage assessment caused by the air pollution in China, through DALY method. Among them, the World Bank (1997; 2007) pointed out that, in China, about 0.178 million people died prematurely from total suspended particulate matter (TSP) in 1995, and about 0.352 million premature deaths in 2003 by $PM_{10}$. According to WHO (Ostro, 2004), about 0.47 million premature deaths in China, during 2008 were related to the $PM_{10}$. Since 2000, Chinese scholars have gradually studied the health hazards of air pollution (Chen et al, 2010). With $PM_{10}$ as the pollution factor, this research group estimated the health loss caused by $PM_{10}$, the annual average concentration exceeded the minimum threshold of 15μg/m$^3$ in more than 600 cities at county level in China from 2004 to 2014. The research found that the number of premature deaths caused by the air pollution in China is between 0.3-0.52 million (Ma et al, 2016). In view of the spatial distribution of air quality monitoring points, these studies used the air quality monitoring data from Chinese cities to assess human health losses caused by the air pollution in these cities. As only human health losses caused by air pollution in cities are assessed, which underestimates the human health losses caused by the air pollution in China.

Remote sensing technology has obvious advantages in $PM_{2.5}$ spatiality and regional transmission monitoring and can provide macroscopic distribution trends, regional distribution and distribution of source and sink. In recent years, scholars have used MODIS satellite AOD data, and linear regression model or mathematical statistical models for remote sensing inversion of near-ground particulate matter concentrations (Kassteele et al, 2006; Pelletier et al, 2007; Kumar et al, 2008; Ma et al, 2016), which filled the gaps of uneven spatial distribution of ground-based monitoring data and insufficient rural monitoring data. Linear regression models are used to establish the empirical relationships between AOD and particulate matters. In the case of Alabama State, US, Wang et al (2003) compared MODIS AOD products to ground $PM_{2.5}$ concentrations. They found that the correlation coefficient R of RMODIS AOD with the corresponding $PM_{2.5}$ hour average was 0.7, and that the correlation coefficient R of the monthly average values of the two reaches 0.92, revealing the great potential of MODIS in air pollution monitoring. Li et al (2005) studied the potential of MODIS AOD and near-ground particulate matters concentration estimation in the early stage. He also compared the MODIS 1km AOD with the Beijing's near-ground $PM_{10}$ concentration (by inversely calculating the air pollution index) and found a certain correlation between the two. These studies didn't perform vertical or humidity correction on AOD data. Zheng et al (2011), Wang et al (2003), Benas et al (2013) made such a correction and found that the correlation between AOD and particulate concentration was significantly improved.

This paper used the MOD04-10KM data of MODIS aerosol products and the $PM_{2.5}$ monitoring data of 338 cities at or above the county level in China in 2017 to perform vertical and humidity correction on AOD data. Then, it reversed China's 10km×10km gridded $PM_{2.5}$ concentration data and grid population, GDP per capita and other data. Next, the DALY index was used to conduct a grid assessment of the economic burdens of human health caused by $PM_{2.5}$ in 2017, such as premature death, hospitalization and disability, and also analyzed the spatial differences in human health loss caused by fine particulate matters in China. This will provide a scientific basis for China to formulate the air pollution prevention and control policies.

# 2. ASSESSMENT METHOD AND DATA SOURCES

## 2.1 Remote sensing inversion of data

After vertical and humidity correction of the aerosol optical depth (AOD), in this paper, we have established the relationship between AOD and near-ground particulate concentration, and then calculated the ground $PM_{2.5}$ concentration using the statistical relations based on the monthly average $PM_{2.5}$ monitoring data of 338 cities at or above the county level in China,

### (1) MODIS data processing

The MOD04-10KM data of MODIS aerosol products in 2017 was used for coordinate transformation, data averaging, etc., to obtain monthly average AOD data of China in 2017.

### (2) Vertical correction

Equation (1) is used to correct the AOD altitude, and obtain the ground extinction coefficient $\beta_0$; for each province, the ground extinction coefficient $\beta_0$ is calculated according to the monthly statistics of the aerosol height H.

$$\tau = \int_0^\infty \beta_z dz = \int_0^\infty \beta_0 * e^{-\frac{Z}{H}} dz = H\beta_0 \qquad (1)$$

### (3) Humidity correction

Based on Vertical correction, humidity correction is made according to Equation (2).

$$\beta_{dry} = \beta_0 / f(RH) \qquad (2)$$

Growth factor $f(RH)=1/(1-RH)$, and $RH$ is the relative humidity of atmosphere.

### (4) Establish a statistical relationship between ground extinction coefficient and $PM_{2.5}$

Integrate $PM_{2.5}$ spatial features into the model. Assuming that the regression parameters in the linear regression model is a function of the geographic position of the observation points, build a k_(a, dry) based $PM_{2.5}$ model for satellite remote sensing estimation.

$$PM_{2.5i} = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_{1k}(u_i, v_i) k_{a,dry_{ik}} + \varepsilon_i \qquad (3)$$

$(\mu_i v_i)$ is the coordinate of sample $i$; $\beta_{1k}$ $(\mu_i v_i)$ is the $k^{th}$ regression parameter of the sample $i$; $p$ is the total number of sample point regression parameters; $\varepsilon_i$ is the error term at the sample $i$, and $\varepsilon_i \sim N(0,\sigma^2)$, $k_{a,dry}$, is near-ground aerosol extinction coefficient.

### (5) Precision test

In this paper, the precision test method based on longitude and latitude is used, and the longitude and latitude data of the national basic site is used to extract the data from the inversion results based on the proximity principle. The data is then compared with the data of basic site for precision verification. Some of the regions were even examined against the data of rural sites. In year 2017, the correlation coefficient $R^2$ between the annual average $PM_{2.5}$ in Chinese cities at or above the county level cities and the remote sensing monitoring result reached 0.82 (Fig. 1). From these cities, the relative error of Tianjin, Guangdong, Fujian, and Guizhou were less than 5% (Fig. 2).

**Fig. 1 Result of remote sensing monitoring of $PM_{2.5}$ average concentration in China in 2017**

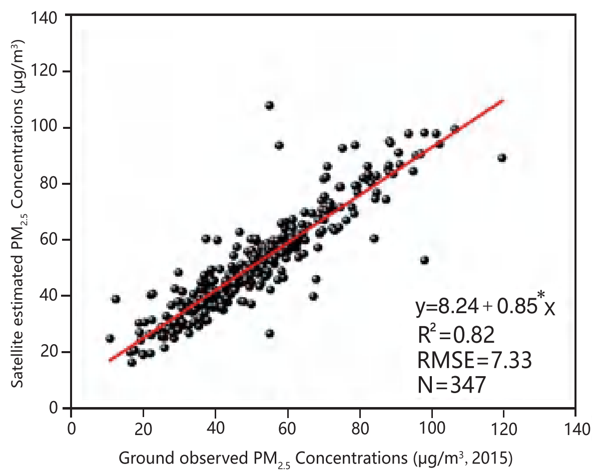
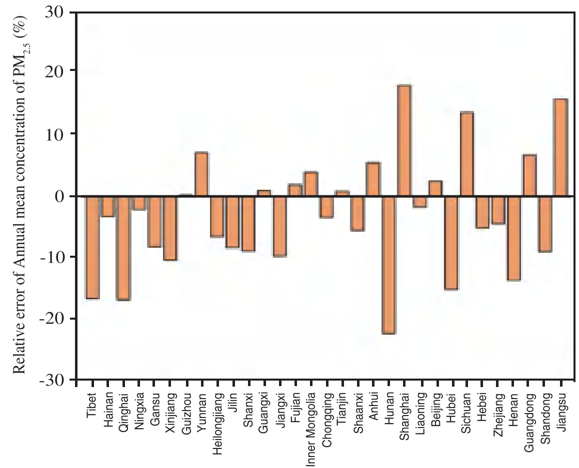



**Fig. 2 Precision analysis of annual mean concentration of $PM_{2.5}$ in China in 2017**




## 2.2 Human health loss caused by air pollution

The indicators of the epidemiological burden caused by environmental factors, includes premature death, increased hospitalization rates due to pollution, outpatient/emergency department visits, birth defects, loss of working days and premature delivery. According to the findings from HEI's PAPA-SAN database, the health effects associated with the air pollution are found to be roughly the same, including acute/chronic respiratory symptoms, changes in lung function, increased cardiopulmonary disease, and lung cancer mortality (Ostro, 2004). Among the health outcomes of chronic effects, research institutions such as WHO and the World Bank all believed that increase in incidence and mortality in exposed populations respiratory system disease and cardiovascular disease, or all-cause mortality, as health outcomes of air pollution (Chen et al, 2013). This paper evaluated such losses as air pollution-caused, all-cause premature deaths, new circulate disease and respiratory disease outpatient visits, as well as disability due to the chronic bronchitis caused by the air pollution.

### (1) Fine particulate matter $PM_{2.5}$ exposure-response relationship

The calculation of "premature deaths or incidence caused by the air pollution" has a probability characteristic, and a statistically probable number of deaths and excess hospitalization rates. Many epidemiologic studies have shown that the relative risk (RR) of air pollutant $PM_{2.5}$ concentrations to healthy terminals generally follows a linear or logarithmic linear relationship. The American Cancer Society (ACS) (Pope et al, 2002) and Harvard Six Cities (Dockey et al, 1993) are classical representatives of the long-term cohort study, and they concluded that once $PM_{2.5}$ concentrations increased by 10μg/m$^3$, all-cause mortality in exposed populations will increase by 4% and 13% respectively. Through research, the concentration of $PM_{2.5}$ in the United States is relatively low, about 25μg/m$^3$, while in China it is usually higher than 50μg/m$^3$. Therefore, the results of the US study, if directly adopted, will overestimate the impact of air pollution on the human health in China. Based on the research by ACS, Jing et al (1999), Xu et al (1996) and Yu et al (2007) constructed a logarithmic linear equation for all-cause health effect and pollutant concentration (LIE) in China. Bernett et al (2014) developed an integrated exposure-response model (IER) to calculate the relative risk of high $PM_{2.5}$ concentration to four health terminals-stroke, chemic heart disease, lung cancer, and chronic obstructive pulmonary disease; Yang et al (2013) and Liu et al (2017) used IER model to calculate the number of premature deaths caused by $PM_{2.5}$ in China. In this paper, Yu Fang's LIE model is used to calculate the number of premature deaths caused by $PM_{2.5}$ in China during year 2017, and the IER model for dose-response relationship uncertainty analysis.

$$RR=［(C+1)/(C_0+1)^{0.075723}］$$

*RR* is the attributable proportion of all-cause relative risk; C is the average concentration of $PM_{2.5}$ in the current year, which is 10km×10km gridded data inverted from the remote sensing data; $C_0$ is the health effect threshold of pollution, i.e., the minimum concentration of the pollutant that is likely to have health impact on human body, which is 10μg/$m^3$ (WHO,2005).

As for the effects of hospitalization, incidence, etc., we used the meta-analysis (Aunan and Pan, 2004) on China, as shown in Table 1.

**Tab. 1 Exposure response relationship of $PM_{2.5}$ and diseases related to air pollution**

| Health terminal | Illness | $\beta$ | Standard deviation |
|---|---|---|---|
| Hospitalization | Respiratory diseases | 0.12 | 0.02 |
| | Cardiovascular diseases | 0.07 | 0.02 |
| Morbidity | Chronic bronchitis diseases | 0.48 | 0.04 |

Note: $\beta$ is the percentage of changes in health hazards caused by changes in the concentration of pollutants per unit (1μg/$m^3$)

## (2) Economic loss from health hazard caused by fine particulate matters

The health loss caused by the air pollution consists of three characteristics: 1) all-cause premature death and death damage caused by air pollution, where economic loss is assessed by human capital approach (Han et al, 2006); 2) Increase in hospitalization rate and rest days of respiratory system and cardiovascular disease patients caused by air pollution and their economic loss, where economic loss is assessed by the disease cost approach; 3) The number of new patients with chronic bronchitis caused by air pollution and their economic loss, where economic loss is assessed by using the approach of disability from disease. The sum of the three is the health loss caused by air pollution.

1) Economic loss from all-cause premature deaths caused by air pollution

$$EC_{a1} = P_{ed} \times GDP_{pc0} \times \sum_{i=1}^{t} \frac{(1+\alpha)^i}{(1+r)^i} \quad (5)$$

$$P_{ed} = (1 - 1/RR) \times f_p P_e \quad (6)$$

$P_{ed}$ is the number of all-cause premature deaths due to the current air pollution level; $t$ is number of years of life lost per capita; $\alpha$ is GDP growth rate per capita; and $r$ is social discount rate. $t$ is 18 years, $\alpha$ is 6.5% and $r$ is 8%(Ministry of Construction, National Development and Reform Commission, 2006). $f_p$ is all-cause mortality at a specific air pollution level, which was 5.76‰ during year 2015, $GDP_{pc0}$ and $P_e$ are the 10km×10km grid per capita GDP and grid exposed population during year 2017. The last two parameters are updated from per capita GDP and population data of 31 provinces, cities and autonomous regions in China in year 2017. They are based on the 1km×1km grid per capita GDP and population data of year 2010 provided by Data Center for Resources and Environmental Sciences of Chinese Academy of Science.

2) Economic loss from disease-caused hospitalization and rest days lost due to air pollution

$$EC_{a2} = P_{eh}(C_h + WD \times C_{wd}) \quad (7)$$

$$P_{eh} = \sum_{i=1}^{n} f_{pi} \frac{\Delta C\beta_i/100}{1 + \Delta C\beta_i/100} \quad (8)$$

$P_{eh}$ is the number of excess hospitalization rate due to the current air pollution level; $C_h$ is the disease-caused hospitalization expenses; and $WD$ is rest days, all of which are from *An Analysis Report of National Health Services Survey in China 2008.* $C_{wd}$ is the off-work costs, equivalent to per capita GDP/365; $r$ is the air pollution-related diseases;and $f_{pi}$ is the hospital admissions at a specific air pollution level, all from *China Health Statistical Yearbook.* $\beta_i$ is the regression coefficient, i.e., percentage of change in health hazard $i$ per unit of change of the pollutant concentration, and ΔC is the difference between the actual pollutant concentration and the pollutant concentration threshold of the health hazard (10μg /m$^3$).

3) Economic loss from chronic bronchitis disability caused by air pollution

$$P_{eb} = (p_e \times r_{COPD})/t \times \frac{\Delta c_i \cdot \beta_i/100}{1 + \Delta c_i \cdot \beta_i/100} \quad (9)$$

$$EC_{a1} = \gamma \cdot P_{eb} \cdot HC_{mu} = \gamma \cdot P_{eb} \cdot GDP_{pc0} \times \sum_{i=1}^{t} \frac{(1+\alpha)^i}{(1+r)^i} \quad (10)$$

$P_{eb}$ is the number of new patients with chronic bronchitis caused by air pollution; $P_e$ is the exposed population; $r_{COPD}$ is the prevalence rate of chronic obstructive pulmonary disease in China, which is 3.3%. $t$ is the average years of life lost due to chronic bronchitis caused by air pollution for a period of 23 years. $\beta_i$ is the regression coefficient, the exposure-response relationship between $PM_{2.5}$ and air pollution related disease is 0.48%. γ is the chronic bronchitis disability loss coefficient, 0.4 (Yu et al, 2009).

## 2.3 Data sources

The data used in this paper mainly comes from MOD04-10KM data of MODIS aerosol product in 2017, 1km×1km grid per capita GDP and population data in year 2010 provided by the Data Center for Resources and Environmental Sciences of Chinese Academy of Sciences, *China Health Statistical Yearbook 2018, An Analysis Report of National Health Services Survey in China 2008, China Statistical Yearbook 2018, and China City Statistical Yearbook 2018.* The key technical parameters in this paper are mainly derived from *Guideline for Chinese Environmental and Economic Accounting.*

# 3. ASSESSMENT RESULTS

## 3.1 Air pollution concentration analysis

China has serious air pollution problem/issue and low percentage of air quality that reaches the standard. In year 2017, among 338 cities at or above the prefecture/county level in China, the air quality of 239 cities failed to meet the standard, accounting for 70.7%. The annual average concentration of $PM_{2.5}$ in Chinese cities obtained from the remote sensing satellite inversion was 42.6μg/$m^3$, and the data provided by China National Environmental Monitoring Center showed that the annual average concentration of $PM_{2.5}$ in Chinese cities was 44.2μg/$m^3$. In this paper, the remote sensing inversion data covers, both urban and rural areas in China, and the air quality in rural areas is relatively better than that in urban areas.

China's air pollution has a significant regional characteristic and complex pollution characteristic. It can be seen from the Fig.3 that the pollution in the Beijing-Tianjin-Hebei region, Yangtze River Delta region, Chengdu-Chongqing region, and Fenhe-Weihe region is relatively serious. In year 2017, the annual average concentration of $PM_{2.5}$ in the Beijing-Tianjin-Hebei region was 51μg/$m^3$, in Yangtze River Delta region was 40μg/$m^3$, in Chengdu-Chongqing region was 37μg/$m^3$, and in Fenhe-Weihe region was 52μg/$m^3$. Affected by sand and dust, the interpretation results of $PM_{2.5}$ concentration on the Taklimakan Desert, Xinjiang were higher. The regions like Aksu, Hotan, Alar, Kashi, and Tumxuk was all above 70μg/$m^3$, and in some local grids exceeded 100μg/$m^3$.

Furthermore, overlay analysis of $PM_{2.5}$ concentration and exposed population finds that in China, only 24.6% of the population was in regions with a $PM_{2.5}$ concentration of less than 35μg/$m^3$ - the national grade II standard, and about 75.4% of the population was exposed to the regions above the national grade II standard; Among them, the proportion of population with $PM_{2.5}$ concentration of 35-50μg/$m^3$ accounted for 40.2%, and the proportion of population with $PM_{2.5}$ concentration of 50-70μg/$m^3$ accounted for 30.7%, and that above 70μg/$m^3$ accounted for 4.5%.

**Fig.3 $PM_{2.5}$ concentration of 10 km×10 km grid in 31 provinces in 2015（μg/$m^3$）**

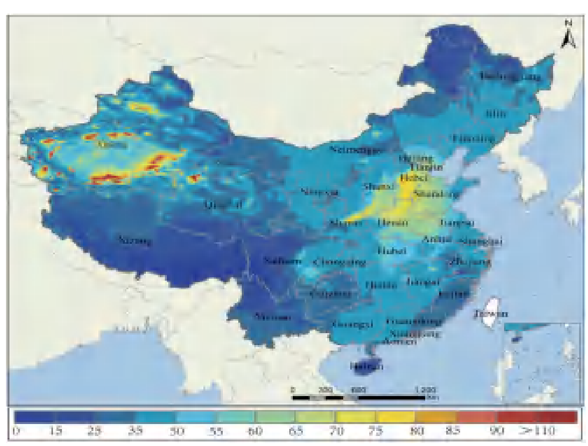
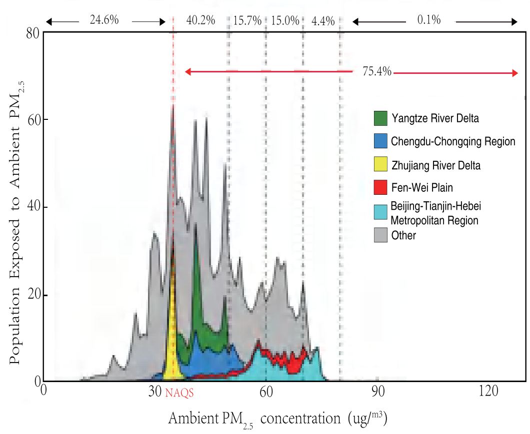


**Fig. 4 National and provincial distribution of population as a function of ambient $PM_{2.5}$ concentration in 2017.**




(Red dash vertical lines indicate the annual concentration limits in China's National Air Quality Standard for Grade II. Grey dash vertical lines demarcate boundaries of population quintiles that apportion the $PM_{2.5}$ concentration distribution with equal number of exposed populations in 2017.)

## 3.2 Human health loss assessment result

The $PM_{2.5}$ concentration data from the remote sensing satellite inversion was used to calculate the human health loss of the exposed population nationwide. The results showed that, in year 2017, the number of premature deaths caused by $PM_{2.5}$ was 0.813 million, and the number of excess hospitalizations of circulatory system & respiratory system diseases was about 1.999 million. In 2017, the total number of deaths in China was 8.82 million, and the number of premature deaths caused by air pollution accounted for 9.2% of the total number of deaths. In regions like Beijing, Xinjiang, Hebei, Shanghai, Tianjin, Anhui, Shanxi, and Guangdong , the number of premature deaths caused by the air pollution accounted for more than 10% of the total number of deaths. In terms of the percentage of premature deaths caused by air pollution over the population of each region, Central China had the highest percentage, 0.64‰; eastern China had the percentage of 0.59‰, and western China was 0.52‰. Among them, Henan (0.73‰) Tianjin (0.72‰) , Hebei (0.71‰) Beijing (0.68‰)and Shanxi (0.68‰) were relatively high, while Tibet (0.18‰), Hainan (0.28‰), Yunnan (0.37‰), Fujian (0.44‰), Guizhou (0.44‰), Guangdong (0.49‰) were relatively low.

Monetization assessment of human health loss caused by air pollution in China was conducted by using the human capital method. The results showed that in 2017, the human health loss caused by $PM_{2.5}$ in China was CNY 1042.84 billion, which accounted for 1.23% of the GDP. Specifically, premature death loss was CNY 895.08 billion, hospitalization loss was CNY 19.97billion, and disability loss was CNY 127.79 billion, accounting for 71.2%, 1.59%, and 10.2% respectively.On different regional scales, human health loss caused by air pollution in eastern China was CNY 692.19 billion, accounting for 45.3%; central China was CNY 331.84 billion, accounting for 26.4%; and in the western China was CNY 232.48 billion, accounting for 18.5%. In provinces like Jiangsu, Shandong, Guangdong, Henan, Zhejiang and Hebei, the human health loss caused by the air pollution was all above CNY 500 billion, where as in provinces like Tibet, Hainan, Qinghai, Ningxia and

Gansu, the human health loss caused by the air pollution was below CNY 10 billion (Fig. 5)and(Fig. 6).

**Fig. 5 The number of premature deaths caused by air pollution in China's 10km ×10km grid in 2017**

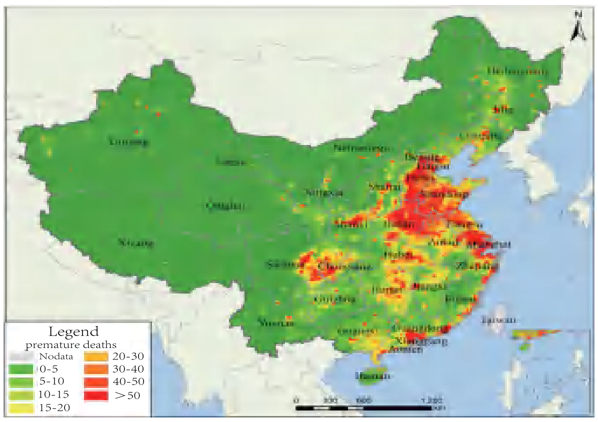
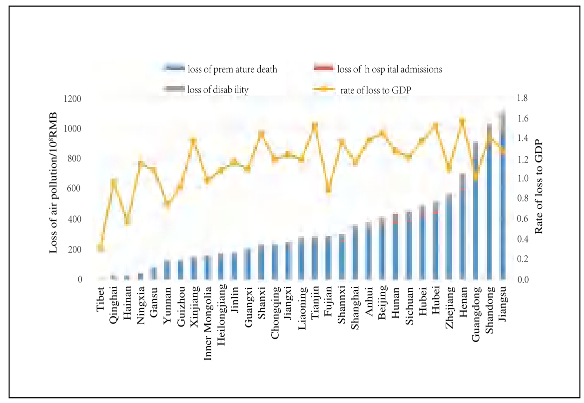



**Fig. 6 Human health loss and its proportion caused by $PM_{2.5}$ in 31 provinces, municipalities and autonomous regions of China**




# 4. DISCUSSIONS AND CONCLUSIONS

## 4.1 Discussions

It is now widely recognized that the monitored data for point locations provide only a partial picture of the air pollution situation in any area, because of the limited spatial representativeness of these sites. Several studies have considered premature mortality induced by long-term $PM_{2.5}$ exposure in China (Cao et al, 2012; Ma et al, 2016; Liu et al, 2016). However, monitoring sites in China are quite sparse and cannot provide the comprehensive and full coverage exposure of data for the entire country, which inhibited the accurate evaluation of the spatio-temporal characteristics of $PM_{2.5}$ pollution over China. To fill the gap between the demand for spatially resolved $PM_{2.5}$ distributions, and the scattered availability of monitoring sites, satellite-derived aerosol optical depth (AOD) have been extensively utilized to estimate the ground-level $PM_{2.5}$ concentrations in China by associating $PM_{2.5}$ concentrations with AOD measurements through statistical models (Zheng et al, 2017). Due to the coverage with cloud and snow, data loss occurs in some regions (Ma et al, 2016). As affected by the sand and dust, remote sensing inversion interpretation results in western Xinjiang are slightly higher.

Establishing the concentration-response relationship of environmental health is a complex research project. In the existing Chinese literature, there is still a lack of large-sample epidemiological cohort findings. Most of the concentration-response uses ecological methodology and has some specific limitations in inferring the causal relationship between air pollution and health in China. The Health Effects Institute (HEI) developed integrated exposure-response model (IER) functions, which were widely applied. HEI used remote sensing inversion data and IER functions to calculate the human health loss caused by $PM_{2.5}$ in China during 2010, and concluded that the outdoor $PM_{2.5}$ pollution during 2010, caused 1.2 million people premature deaths and over 25 million years lived with disability (Yang et al, 2013). In this paper, the $PM_{2.5}$ satellite remote sensing interpretation results of the research group and the IER dose-response model of HEI were used to calculate the number of premature deaths caused by $PM_{2.5}$ in China in year 2015. The research group also found that the number of premature deaths caused by air pollution in China during 2017 was about 0.87 million, 7% higher than the calculation results of the LIE model adopted in this paper.

This paper used ground-based monitored $PM_{2.5}$ concentration data of 338 cities at or above the prefecture/county level and calculated the number of premature deaths among exposed population in urban areas was about 0.488 million, close to the findings of WHO, World Bank, on the number of premature deaths caused by the air pollution in urban areas of China. In China, the air quality in rural areas is far better than in urban areas, and exposed populations in rural areas are less than urban areas; and the number of premature deaths caused by air pollution in rural areas is reasonably smaller than that in urban areas. Therefore, we believe that HEI might have overestimated the human health loss caused by air pollution in China, possibly this is due to the higher remote sensing inversion air pollution data.

There are two economic valuation of premature death caused by air pollution, which are human capital approach and value of a statistical life (VSL). VSL is deduced from their answers and used to value postponed deaths. Empirical assessments have provided a range of values in different countries. The cost of reducing the risk of premature death caused by air pollution in China is about \$150000 (Zeng and Jiang, 2010), and the results of the willingness to pay survey in France and Italy were \$1.25 million and \$870,000 (Alberini et al, 2004). A key finding from this literature is that the VSL depends on the characteristics of the risk of death: age at death, time between exposure and death, and nature of the underlying risk that have largely been found to be relevant factors (Pascal et al, 2013). In this paper, human capital approach was used to assess the economic valuation of premature death caused by the air pollution, which is lower than VSL.

## 4.2 Conclusions

The MOD04-10KM data of MODIS aerosol products in 2017 was used to invert 10km×10km grid $PM_{2.5}$ concentration data, the results show that the annual average concentration $PM_{2.5}$ in China in year 2017 was 42.6μg/m$^3$, 1.6μg/m$^3$ lower than China's city-based environmental monitoring concentration. Approximately 75.4% of the Chinese population is exposed to the regions, where the $PM_{2.5}$ concentration above the national grade II standard. The population with $PM_{2.5}$ concentration of 35-50μg/m$^3$ accounted for 40.2%; the population with $PM_{2.5}$ concentration of 50-70μg/m$^3$ accounted for 30.7%, and while the population with 70μg/m$^3$ or above accounted for 4.5%. In year 2017, the number of premature deaths caused by $PM_{2.5}$ nationwide was approximately about 0.813 million, and the number of

excess hospital admissions of circulatory system & respiratory system diseases was almost 1.999 million. China's human health loss caused by $PM_{2.5}$ was CNY 1042.84 billion, accounting for 1.48% of GDP. Specifically, the number of premature death loss was CNY 895.06 billion; hospitalization loss CNY 19.97 billion, and disability loss was CNY 127.79 billion, accounting for 71.2%, 1.59% and 10.2% respectively.

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