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Original Research Paper

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Total Amount Calculation and Health Benefit Assessment of $PM_{2.5}$ Adsorbed by Urban Green Space in Xuzhou City, China

HuanXu and Hong Li†
Dept. of Landscape Architecture, City and Environment College, Jiangsu Normal University, Xuzhou 221116, China
†Corresponding author: Hong Li

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ABSTRACT

According to analysis of authoritative data and previous research results, the total amount of $PM_{2.5}$ adsorbed by urban green space was measured in Xuzhou, and its health benefit was assessed through Poisson regression model and environmental health evaluation, also health benefit per unit area of different green space types were compared and analysed in this study. The results showed that the total amount of $PM_{2.5}$ adsorbed by urban green space was 8693.64kg annually in Xuzhou, 198.8 cases of harmful diseases can be reduced average daily, including 89.8 cases of sickness, 100.6 cases of outpatient, 6.8 cases of hospitalization and 1.6 cases of early death; the annual health benefit from decreases of $PM_{2.5}$ concentration is about 2.31 billion CNY, which is equal to 0.47% of Xuzhou's GDP in 2014; health benefit per unit area of arbor-shrub-herb is the highest, 28.57 CNY and lawn is lowest, 0.14CNY. Therefore, to appropriately reduce the lawn area, change part of lawn into composite structures of green space such as shrub-herb and arbor-herb is helpful to enhance the efficiency of $PM_{2.5}$ absorbed by urban green space, make the quality of urban air better, and further to improve health benefit of urban green space.

INTRODUCTION

Fine particulate matter ($PM_{2.5}$) refers to the particles with the aerodynamic equivalent diameter no more than 2.5 micrometers. It can suspend in the air for a long time, which has small particle size, contain plenty of poisonous and harmful substances and can be transmitted over a long distance. It is also one of the major air pollutants to endanger human body health and the atmosphere quality, which even becomes the primary environmental restrictions of the development of city and people's happy life. It has been shown that fine particulate matter can compromise the respiratory system and immune system, and cause respiratory disease, cardiovascular disease and other diseases, which will increase mortality (Xie et al. 2009, Chen et al. 2010). The mortality risk of lung cancer, heart disease and all death causes will increase 8%, 6% and 4% respectively when the concentration of $PM_{2.5}$ increased 10μg (Pope et al. 2002).

At this stage, the study of $PM_{2.5}$ mainly concentrates on composition (Cao et al. 2014), characteristics (Wang et al. 2012, Li et al. 2015), source apportionment (Lin et al. 2016, Wang et al. 2015), and transmission route (Sheng et al. 2014), as well as the simulation study of predicting PM2.5 concentration (Dong et al. 2009, Liu et al. 2015). There are plenty of studies on dust-retention ability and efficiency of plant in urban green space (Wang et al. 2014, Zhang et al. 2015, Li et al. 2015, Xiao et al. 2015), the plants have an obvious inhibiting and adsorptive effect on the particulate matter in the air. In related quantitative research of which, Nowark et al. (2006) estimated that the total amount of PM_{10} absorbed by urban vegetation was 214,900 tons every year in the United States; Powe et al. (2004) assessed that the plants absorbed about 85695-85695 tons of PM_{10} and about 7715-7715 tons of SO_2 per year in the UK; Tong et al. (2015) estimated that the Beijing road green belts absorbed 1.09 tons of $PM_{2.5}$ in total per year. However, there are still few studies about the amount of $PM_{2.5}$ which is absorbed by urban green space and its connection with health benefit. Therefore, based on the measured results of the amount of $PM_{2.5}$ absorbed by urban green space, this article estimates the total amount of $PM_{2.5}$ absorbed by Xuzhou green space and assess its health benefits through Poisson regression model and environmental health evaluation method, which provide important basis for enhancing health benefits of urban green space and the management of regional fog and haze.

MATERIALS AND METHODS

Study area: Xuzhou city is located in the southeast of North China Plain, which is on the alluvial flatlands flooded by the Yellow River. By the end of 2014, there are 255km^2 of structure area, and 8.628 million permanent population which includes 5.13 million urban permanent population (Xuzhou Statistics Bureau 2015). The city proper is located on both sides of ancient yellow river, and there is dry climate and less rainfall, for which alluvial silt soil causes dry dust. At the same time, because the city proper is surrounded by mountains and has an obvious effect of basin, it is not easy for dilution and diffusion of the pollutants over the city, especially at a low altitude. The climate in Xuzhou city is a semi-humid continental climate in the warm temperate zone, which has obvious characteristics of the northern climate. The frequency of calm wind is high which is annually at an average of 20%. The precipitation is more in the summer and less in the spring and autumn which has a low clean-up effect for the pollutants in the air. Hence, Xuzhou city has serious pollution of fine particulate matter.

Total amount calculation methods: Plants of green space have three ways to block and absorb $PM_{2.5}$, which are parking, adhesion and adsorption; parking is that when air current with dust goes though plants, particles with a large diameter lose power and fall down to the ground, at the same time, particles with a small diameter are blocked and suspend among the plant community space; adhesion refers to the special structure on the surface of blades and the wettability of transpiration which can intercept atmospheric particulate matter; adsorption means that oil and juice secreted by stems and leaves of plants can absorb lots of dust (Zhao et al. 2013, Zhang et al. 2015). The plants exist as communities in urban green space, and different types of plants have colossal differences of effects to block and absorb particles (Yu et al. 2009), thus, based on the community structural characteristics of urban green space and the results of the study under the condition of no wind (Luo 2013, Wang et al. 2014, Li et al. 2014, Zhao 2015), computational formula to calculate the amount of $PM_{2.5}$ absorbed by urban green space in Xuzhou is as follows:

$$M_i = S_i \cdot H_i \cdot C_i \quad ...(1)$$

$$SM = D \cdot \sum_{i=1}^{7} M_i \quad ...(2)$$

Where M_i is the amount of $PM_{2.5}$ absorbed by the i type of urban green space each day (in µg); S_i is the area of the i type of urban green space (in m^2); H_i is the effective height of the i type of urban green space (in m); C_i is the amount of $PM_{2.5}$ absorbed by the i type of urban green space under no wind condition (in µg/m^3); SM is the amount of $PM_{2.5}$ absorbed by the i type of urban green space annual in Xuzhou city (in µg); D is effective day (in d); i is the type of urban green space.

Assessment method of health benefit: Based on the environmental health evaluation theory, there are two steps to evaluate health benefits taken by absorption of $PM_{2.5}$. Firstly, we need to analyse and measure health risk changes of various health terminals caused by decreases of $PM_{2.5}$ (Equation 3), then make monetary evaluations and calculate financial benefits caused by health improvement (Equation 4). The amount of health risk changes of various health terminal is calculated by environmental health risk assessment, which is usually combined with exposure - response relationship between pollutant concentration and health effects from epidemiologic studies, and estimated by Poisson regression model (Huang et al. 2013). The evaluation model is as follows:

$$E_i = P\left[1 - \frac{1}{\exp(\beta \cdot \Delta C)}\right] e_i \quad ...(3)$$

$$L = \sum_{i=1}^{n} L_i = \sum_{i=1}^{n} E_i \cdot L_{pi} \quad ...(4)$$

Where L is the total amount of health benefits caused by the decreases of $PM_{2.5}$ concentration (in10^4 CNY); L_i is the health benefits of health terminal I (in 10^4 CNY); E_i is the amount of health risk changes of health terminal i; L_{pi} is the corresponding value of health risk change of health terminal I (in 10^4CNY/case); P is the number of permanent residents, with ten thousand people as the unit; β is the coefficient of exposure-response relationship; ΔC is the variation of $PM_{2.5}$ concentration caused by urban green space (in µg/m^3·d); e_i is the health effects of health terminali in the actual concentration; n is the number of health terminals.

When we calculate the variation of $PM_{2.5}$ concentration blocked and absorbed by urban green space, the study methods of Wang et al. (2006) and Nowak et al. (2013) can be referred, the calculating equation is as follows:

$$\Delta C = \frac{SM}{BA \cdot AT \cdot L} \quad ...(5)$$

Where ΔC is the variation of $PM_{2.5}$ concentration absorbed by urban green space (in µg/m^3·d); SM is the total amount of $PM_{2.5}$ absorbed by the i type of urban green space annual in Xuzhou city (in µg); BA is built-up area of Xuzhou city (in m^2); AT is the thickness of the atmosphere with high pollution concentration (in m); D is the number of days in a year (in d).

RESULTS AND DISCUSSION

Total amount of PM2.5 absorbed by urban green space: From the statistical data of Xuzhou statistical yearbook and Xuzhou Bureau of Parks, the percentage of greenery coverage is 43.3% in Xuzhou build-up area, the green space area of build-up area is 11,040hm^2. There are different community structures of green space, including 7 types, such as arbor-shrub-herb, arbor-shrub, arbor-herb, shrub-herb, single arbor, single shrub, and lawn (Table 1). Among them, the area of arbor-shrub-herb accounted for the largest

Table 1: Component types of urban green space in Xuzhou city.

Component type	Arbor-shrub-herb	Arbor-shrub	Arbor-herb	Shrub-herb	Single arbor	Single shrub	Lawn
Area (hm^2)	6884.54	576.29	324.58	1455.07	291.46	71.76	1436.30
Proportion (%)	62.36%	5.22%	2.94%	13.18%	2.64%	0.65%	13.01%

Table 2: $PM_{2.5}$ adsorption value and effective height of different component types.

Component type	Arbor-shrub-herb	Arbor-shrub	Arbor-herb	Shrub-herb	Single arbor	Single shrub	Lawn
Effective height (m)	7	7	6.5	3	6	3	0.1
adsorption value (μg/m^3)	70.1	56.08	47.16	43.53	37.1	34.82	23.2

Table 3: Statistical analysis of the essential climatic conditions in Xuzhou city.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of days	31	28	31	30	31	30	31	31	30	31	30	31
Average temperature(°)	0.4	2.7	8.0	15.1	20.6	25.0	27.1	26.3	21.7	15.7	8.5	2.6
Average precipitation days	4.0	5.4	6.4	7.1	7.4	8.0	13.5	9.9	7.2	6.8	5.1	3.7

*The above data is according to the statistics from 1971 to 2014.

(62.36%), secondly for shrub-herb (13.18%), and followed by lawn (13.01%), arbor-shrub (5.22%), arbor-herb (2.94%), single arbor (2.64%), the least is the area of single shrub (0.65%).

According to the report on the state of Xuzhou's environment in 2014, the mean annual concentration of $PM_{2.5}$ is 67μg/m^3 in the city proper and referring to the study results from Yin et al. (2007), Wu et al. (2008), Luo et al. (2013), Wang et al. (2014) and Zhao et al. (2015), the $PM_{2.5}$ adsorption value of different community structures and its effective height were derived in Table 2. The existing research results are short of research data of arbor-shrub and single shrub, the area of which are less, and the structures of arbor-shrub and single shrub are similar to the structures of arbor-shrub-herb and shrub-herb respectively. So we can make the value of arbor-shrub and single shrub equal to the value of arbor-shrub-herb and shrub-herb which times 0.8.

Xuzhou green space dominated by deciduous species, so evergreen species probably accounted for 25%, deciduous species accounted for 75%. In the winter, blade of deciduous species dry and fall down to the ground, and it blocks and absorbs few amounts of $PM_{2.5}$ (Ji et al. 2013), meanwhile, the absorption ability of evergreen species are weakened among plant communities. Furthermore rainfall and components of haze have a significant negative correlation (Tai et al. 2010), which can efficiently reduce $PM_{2.5}$ concentration. So, the effective adsorption time of $PM_{2.5}$ by urban green space is defined as the sum of non-rainfall days in the spring, summer and autumn and the 20% of non-precipitation days in the winter. According to the statistical data for many years from Xuzhou Meteorological Bureau (Table 3), the mean rainfall days in the spring, summer, and autumn (March-November) is 71.4 days in Xuzhou, in which effective time are 203.6 days. The mean precipitation days in the winter (December-February) is 13.1 days in Xuzhou, in which effective time are 15.4 days. So the effective time for the whole year is 219 days.

From Equation (1) and Equation (2), the daily reduction of $PM_{2.5}$ absorbed by Xuzhou green space is 39.697kg (Fig. 1), and the annual amount is 8693.64kg, in which the absorption ability of arbor-shrub-herb is strongest, and its amount of reduction is the most up to 7398.35kg, which account for 85.1%; the amount of reduction by arbor-shrub and shrub-herb are 495.44kg and 416.14kg, which account for 5.7% and 4.8% respectively; the amount of reduction by arbor-herb and single arbor are 217.90kg and 142.09kg, which respectively account for 2.5% and 1.6%; the percentage of reduction by single shrub (16.42kg) and lawn (7.30kg) are the least, which are separately 0.2% and 0.1%. The above results show that, urban green space should be mainly combined with arbor-shrub-herb, arbor-shrub or shrub-herb.

Health risk changes caused by decreases of $PM_{2.5}$: Referring to ICD-10 and domestic studies of the health benefits which have been reported, and considering the current research status of domestic epidemiology and the accessibility of data, the health terminals about $PM_{2.5}$ pollution were selected from four categories, including sickness, outpa-

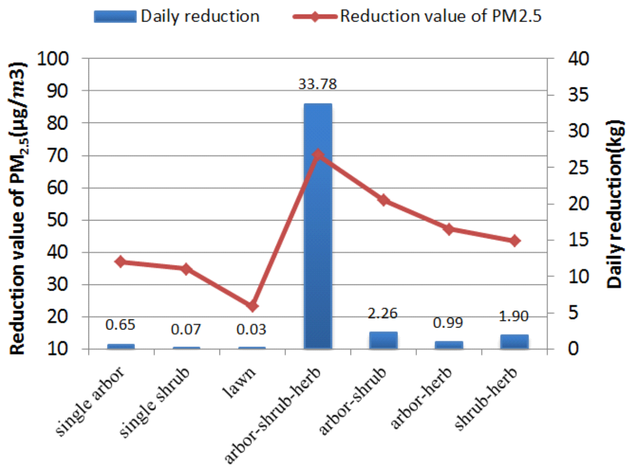

Fig. 1: Daily reduction of different types of green space.

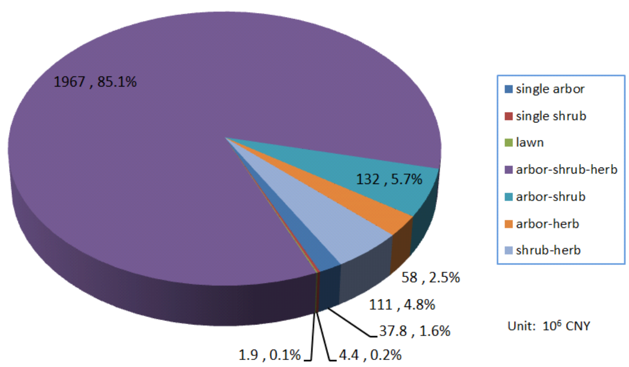

Fig. 2: The health benefit of different green space types.

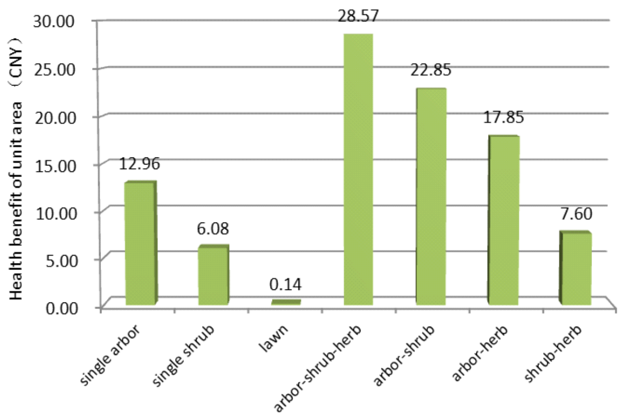

Fig. 3: Unit area health benefit of different green space types.

tient, hospitalization and early death, in which the sickness includes asthma, chronic bronchitis and acute bronchitis; the outpatient includes pediatric outpatient and internal medicine outpatient; the hospitalization includes cardiovascular disease and respiratory disease; early death includes acute death, cardiovascular disease death (chronic) and respiratory disease death (chronic). To avoid double counting, hospitalization of respiratory disease excludes asthma, chronic bronchitis and acute bronchitis. Integrating study results of health benefit assessment of $PM_{2.5}$ reported by Kan et al. (2002), Xie et al. (2009), Liu et al. (2010), Xie et al. (2014), exposure - response coefficients and reference incidence rates of various health terminals are summarized as shown in Table 4.

Firstly, the average daily changes of $PM_{2.5}$ concentration is calculated by the Eq. (5), in which, the annual amount of $PM_{2.5}$ absorbed by urban green space is 8693.64kg. The thickness of the atmosphere with higher $PM_{2.5}$ concentration is 350m according to the research data of Jiangsu Environmental Protection Bureau, the number of days in a year is 365, the build-up area in Xuzhou city is 255km^2. So the amount of average daily changes (ΔC) is 0.2668 μg/(m^3·d).

Secondly, the amount of health risk changes caused by decrease of $PM_{2.5}$ is calculated by the Eq. (3), in which, the number of permanent residents is 5.13 million, the value of β and e_i can be found in the Table 4. The calculation results are shown in Table 5, the decreases of $PM_{2.5}$ concentration caused by urban green space has a significant impact of residents health in Xuzhou, 198.8 cases of harmful diseases can be reduced average per day, including 1.6 cases of early death, 33.8 cases of asthma, 9.1 cases of chronic bronchitis, 46.9 cases of acute bronchitis, 29.8 cases of pediatric outpatient, 70.8 cases of internal medicine outpatient, 2.3 and 4.5 cases of hospitalization for cardiovascular and respiratory disease. Thus it can be seen, urban green space can to some extent reduce the incidence of acute bronchitis and asthma of urban residents, which also has a large effect on pediatric and internal medicine outpatient.

Health benefits from decreases of $PM_{2.5}$: At present human capital approach (HCA), willingness to pay (WTP) or cost of illness (COI) is mainly adopted to monetize health effects caused by air pollution in international and domestic related studies. Referring to the study methods and data of Kan et al. (2004), Liu et al. (2010), Zhang et al. (2007), as well as the per capita disposable income growth of Beijing in 2013 and 2014 and the per capita disposable income ratio of Xuzhou and Beijing in 2014, the existing research results of Beijing in 2012 are revised to the economic loss of various health terminals of Xuzhou in 2014 after the adjustment of income level (Table 6).

After monetizing health risk changes of various health terminals, the average daily health benefit from decreases of $PM_{2.5}$ concentration in Xuzhou is about 6.33 million CNY, and the annual health benefit is about 2.31 billion CNY, which is equal to 0.47% of Xuzhou's GDP in 2014. Among

Table 4: Exposure-response coefficients and reference incidence rates of various health terminals.

	Health terminals	β (95%confidence interval) (%)	e (‰)
Sickness	Asthma	2.10 (1.45,2.74)	0.1536986
	Chronic bronchitis	10.09 (3.66,15.59)	0.0190137
	Acute bronchitis	7.90 (2.7,13)	0.1041096
Outpatient	Pediatric outpatient	0.56 (0.2, 0.9)	0.4191781
	Internal medicine outpatient	0.49 (0.27,0.7)	1.1261644
Hospitalization	Cardiovascular disease	0.68 (0.43,0.93)	0.0270904
	Respiratory disease	1.09 (0, 2.21)	0.0350411
Early death	Acute death	0.40 (0.19,0.62)	0.0161644
	Cardiovascular disease death	0.53 (0.15,0.9)	0.0075230
	Respiratory disease death	1.43 (0.85,2.01)	0.0017025

Note: β is the percentage of increased morbidity and mortality when $PM_{2.5}$ concentration was increased by 10μg/m^3; e is calculated by converting annual mortality and morbidity into daily mortality and morbidity.

Table 5: Health risk changes of various health terminals.

	Health terminals	Health risk changes (cases)
Sickness	Asthma	33.8 (25.3, 40.9)
	Chronic bronchitis	9.1 (6.1, 9.6)
	Acute bronchitis	46.9 (27.4, 51.7)
Outpatient	Pediatric outpatient	29.8 (11.2, 45.9)
	Internal medicine outpatient	70.8 (40.2, 98.4)
Hospitalization	Cardiovascular disease	2.3 (1.5, 3.1)
	Respiratory disease	4.5 (0, 8.0)
Early death	Acute death	0.8 (0.4, 1.3)
	Cardiovascular disease death	0.5 (0.2, 0.8)
	Respiratory disease death	0.3 (0.2, 0.4)
	Total	198.8 (112.4,260.1)

Table 6: Economic loss and average daily health benefits of various health terminals.

	Health terminals	Economic loss (×10^{4}CNY/case)		Health benefits (×10^{4}CNY)
		Beijing (2012)	Xuzhou (2014)	
Sickness	Asthma	1.06	0.70	23.68(17.71,28.63)
	Chronic bronchitis	53.8	35.54	323.13(216.07,341.20)
	Acute bronchitis	0.52	0.34	16.11(9.42,17.77)
Outpatient	Pediatric outpatient	0.06	0.04	1.18(0.44,1.82)
	Internal medicine outpatient	0.06	0.04	2.81(1.59,3.90)
Hospitalization	Cardiovascular disease	2.87	1.90	4.37(2.86,5.79)
	Respiratory disease	1.86	1.23	5.57(0.00,9.84)
Early death	Acute death	238.8	157.73	132.39(64.65,199.41)
	Cardiovascular disease death	238.8	157.73	80.27(23.88,129.94)
	Respiratory disease death	238.8	157.73	43.69(27.95,57.18)
	Total	-		633.21(364.57,795.47)

Note: In 2013 and 2014 the per capita disposable income of Beijing increased by 10.6% and 8.9% respectively, so urban per capita disposable income of Beijing and Xuzhou were 43,910 CNY and 24,080 CNY respectively in 2014.

this, the health benefit from reduction of sickness is 1 billion 325 million CNY (57.33%), the early death is 935 million CNY (40.46%), the hospitalization is 36 million CNY (1.56%), and the outpatient is 15 million CNY (0.65%). The results show that urban green space has an evident influence on health benefits of the reduction of sickness and early death. Reducing the number of outpatient cases are the most, which has a lowest unit value of economic loss, so its amount of health benefit is the lowest.

DISCUSSION

From health benefit of different green space types in Xuzhou, the health benefit of arbor-shrub-herb is the highest, for 1 billion 967 million CNY, which account for 85.1% of the total benefit value; the second highest is the health benefit of arbor-shrub, which is 132 million CNY and account for 5.7%; and then followed by shrub-herb is 111 million CNY(4.8%), arbor-herb is 58 million CNY (2.5%), single arbor is 37.8 million CNY(1.6%); the health benefit of single shrub and lawn are the lowest, for 4.4 million CNY (0.2%) and 1.9 million CNY (0.1%) respectively.

Based on areas of different green space types in Xuzhou, the health benefit of different green space types were converted into health benefit of unit area as shown in Fig. 3. Unit area health benefit of arbor-shrub-herb is the highest, 28.57 CNY, the next is arbor-shrub and arbor-herb, which are respectively 22.85 CNY and 17.85 CNY. Then it is followed by single arbor (12.96 CNY), shrub-herb (7.60 CNY), single shrub (6.08 CNY), and lawn is lowest, 0.14 CNY. Therefore, it is concluded that to appropriately reduce the lawn area, change part of lawn into composite structures of green space such as shrub-herb and arbor-herb, to improve the structure level of urban green space is helpful to enhance the efficiency of $PM_{2.5}$ absorbed by urban green space, and further to improve health benefit of urban green space and make the quality of urban air better.

It is important to note that accuracy value of $PM_{2.5}$ absorbed by different green space structures is influenced by various factors, such as meteorological condition, observation position and equipment. Even for the same structure of green space is also has a large differences, so there is a certain error in the study results, which need to be amended through more field observation in the later. In the aspect of health risk changes, some scholars have brought up that the exposure-response coefficients are usually more accurate when data are derived from the medical institutions of distinguishing diseases in more detail (Aunan et al. 2004). Because the outpatient and emergency of Chinese medical institutions do not distinguish diseases strictly, outpatient health terminal only can be distinguished by ages as pediatric and internal medicine outpatient, it is health risk changes are likely to be underestimated in this study. In addition, the 95% confidence interval of exposure-response coefficients are applied to calculate the health risk changes and health benefit assessment, so as to better reflect error range caused by the data uncertainty.

CONCLUSIONS

By analysing data from Statistics Bureau, Bureau of Parks, Meteorological Bureau in Xuzhou city, and concluding study results of $PM_{2.5}$ value absorbed by different green space structures, the calculation results show that the effective adsorption time of $PM_{2.5}$ for the whole year is 219 days, and the annual amount of $PM_{2.5}$ absorbed by urban green space in Xuzhou is 8693.64kg, in which the absorption ability of arbor-shrub-herb is strongest, which account for 85.1%, followed by arbor-shrub (5.7%), shrub-herb (4.8%), arbor-herb (2.5%), single arbor (1.6%), single shrub (0.2%) and lawn (0.1%). In order to make the urban green space has best adsorption ability, urban green space should be mainly combined with arbor-shrub-herb, arbor-shrub or shrub-herb.

The health risk changes caused by decreases of $PM_{2.5}$ is calculated by the Poisson regression model, the results show that the decreases of $PM_{2.5}$ concentration caused by urban green space has a significant impact of residents health in Xuzhou, 198.8 cases of harmful diseases can be reduced average daily, including 1.6 cases of early death, 33.8 cases of asthma, 9.1 cases of chronic bronchitis, 46.9 cases of acute bronchitis, 29.8 cases of pediatric outpatient, 70.8 cases of internal medicine outpatient, 2.3 and 4.5 cases of hospitalization for cardiovascular and respiratory disease. Urban green space can to some extent reduce the incidence of acute bronchitis and asthma of urban residents, which also has a large effect on pediatric and internal medicine outpatient.

After monetizing health risk changes of various health terminals, the average daily health benefit from decreases of $PM_{2.5}$ concentration in Xuzhou is about 6.33 million CNY, and the annual health benefit is about 2.31 billion CNY, which is equal to 0.47% of Xuzhou's GDP in 2014. Among this, the health benefit from reduction of sickness is 1 billion 325 million CNY (57.33%), early death is 935 million CNY (40.46%), hospitalization is 36 million CNY (1.56%), and outpatient is 15 million CNY (0.65%). The results show that urban green space has an evident influence on health benefits of the reduction of acute and chronic bronchitis and asthma.

From unit area health benefit of different green space types in Xuzhou, Unit area health benefit of arbor-shrub-herb is the highest, 28.57 CNY, the next is arbor-shrub (22.85 CNY), then it is followed by arbor-herb (17.85 CNY), single arbor (12.96 CNY), shrub-herb (7.60 CNY), single shrub (6.08 CNY), and lawn (0.14 CNY). Therefore, it is concluded that to appropriately reduce the lawn area, change part of lawn into composite structures of green space such as shrub-herb and arbor-herb, to improve the structure level of urban green space is helpful to enhance the efficiency of $PM_{2.5}$ absorbed by urban green space, make the quality of urban air better, and further to improve health benefit of urban green space.

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