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Temporal and Spatial Variation Characteristics of Air Pollution and Prevention and Control Measures: Evidence from Anhui Province, China

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ABSTRACT

The rapid advancement of industrialization and urbanization has caused air pollution and increased the pressure on the urban ecological environment. Meanwhile, the unreasonable energy structure, emissions of pollution sources by chemical enterprises, and motor vehicle exhaust have aggravated the air pollution in urban areas. To analyse the temporal and spatial variation characteristics of air pollution and propose specific prevention and control measures for air pollution, taking Anhui Province in China as an example, this study analyses the causes of air pollution by using the air pollution index (API) data of Anhui Province obtained from 2013 to 2015. A comparative analysis is conducted on the API data from 2013 to 2015, and air quality in different cities of Anhui Province in 2015 is evaluated. Results show that unreasonable energy structure, accelerated urban infrastructure construction, and increasing motor vehicle emissions are the main cause of air pollution in Anhui Province. From temporal and spatial perspectives, the average APIs of different cities in Anhui Province from 2013 to 2015 were 64.8, 73.2 and 70.8 respectively. These values reveal the overall fluctuating growth trend of air pollution. From the spatial perspective, the number of days with good air quality in 14 cities of Anhui Province in 2015 ranged from 262 days to 365 days, which accounted for 71.8% to 100% of the total days in a year. It reflects that the degree of urban air pollution in northern Anhui is higher than that in southern Anhui. The conclusions reveal the temporal and spatial variation characteristics of air pollution, and provide policy suggestions for formulating scientific air pollution control measures, effectively implementing air pollution management and improving the current air pollution status.

INTRODUCTION

Air pollution refers to the phenomenon in which the concentration of air pollutants or secondary pollutants converted from the primary air pollutants reach a level at which they harm human health and the natural environment. Air pollution is a result of natural processes (e.g., volcanic eruptions and forest fires) and human factors (e.g., industrial waste gas, use of coal for daily life, automobile exhaust and nuclear explosions). Its main process is composed of three links, namely, pollutant emissions, atmospheric transmission, and humans and the environment. The rapid increase in the number of cars in recent decades has led to an increase in automobile exhaust emissions and photochemical pollution, both of which aggravate air pollution. The main pollutants in air are atmospheric aerosol, sulphur dioxide, nitrogen dioxide, carbon monoxide, chlorine gas and photochemical smog. Therefore, air pollution is one of the most pressing environmental problems in the world.

With the rapid development of the national economy, enlargement of the city scale, and construction of various urban engineering structures in Anhui Province, the urban air quality in the region has become a problem and is attracting increasing attention. Continuous rapid economic growth increases environmental pressure and triggers long-term environmental risks. As a result, the air quality in several large and medium-sized cities in Anhui Province is deteriorating. The increase in air pollution sources and environmental pollutants and expansion of the pollution scope exacerbates air pollution, and the amount of SO_2, NOx and total suspended particles (TSP) as the main pollutants increases. Severe air pollution significantly affects the environment and poses a threat to sustainable development. As living standards continue to improve, the demand for a high-quality living environment and awareness about environmental protection increases. Considering that the degree of air cleanliness directly affects people's activities, the general public, with obvious regard for their health and safety, pays close attention to the environmental quality in the cities they live in. The present study regards Anhui Province in China as an example to analyse the causes of air pollution and study its temporal and spatial variation characteristics. The analysis aims to provide timely, accurate, and comprehensive environmental quality information for environmental management decision making, strengthen environmental pollution control and prevent the occurrence of serious pollution events.

EARLIER STUDIES

In the 20th century, which was characterized by the acceleration of global industrialization and urbanization, large-scale environmental and air pollution incidents were frequently recorded in the Western developed countries. These air pollution incidents elicited extensive public concern. To solve this problem, leaders of developed countries formulated a series of laws, standards, and control measures. With regard to the present situation of air pollution and its temporal and spatial variation, Khanna presented a new air pollution index (API) system by performing a comprehensive evaluation of various pollutants. The researcher compared the developed API system with the pollutant standard index (PSI) of the U.S. Environmental Protection Agency and concluded that the API system can effectively reflect the damage caused by polluted gases on the human body (Khanna 2000). Querol et al. conducted a statistical analysis on the concentrations of PM10 and PM2.5 in urban and rural areas and along roads in seven regions of Europe; they argued that climate, long-distance transmission, and traffic characteristics in winter are the main factors that affect PM10 and PM2.5 (Querol et al. 2004). Karaca analysed 86 days' worth of data in Istanbul in July 2002 and July 2003 and concluded that the average concentration of absorbable particles in air during the study period conformed to the air quality standard of Turkey; however, the average concentration was higher than that in the EU standard, and the concentration of fine particles was higher than that in the U.S. Standard (Karaca et al. 2005). Gupta selected four cities in India to analyse the variation law of the average values of PM10 in 10 years and pointed out that PM10 in the four cities shows a decreasing or stable trend (Gupta et al. 2006). Kyrkilis argued that API is more effective than PSI in revealing the impact of pollution on health (Kyrkilis et al. 2007). Grivas analysed the seasonal change in PM10 in eight cities around Athens and found that four regions near the city are affected by urban primary aerosol, fuel combustion and automobile exhaust (Grivas et al. 2008). Pope believed that the concentration of air pollutants is temporarily dynamic and exhibits spatial heterogeneity. By examining air pollution in Phoenix, U.S., he found that the spatial pattern distribution of ozone and PM10 is related to the selection of the time scale (Pope et al. 2014). Li analysed the temporal and spatial variations in API in Guangzhou, China, and concluded that meteorological factors exert a significant influence on air pollution (Li et al. 2014). Rodriguez screened relevant air pollution indexes by using the averaging method of the Bayesian model and reported that air pollution is closely related to urban structure based on economic, population and meteorological conditions (Rodríguez et al. 2016). With regard to prevention and control of air pollution, Chen analysed how China adopts comprehensive measures to address air pollution (Chen et al. 2013). Kanada analysed the long-term influence of the air pollution prevention and control policy adopted by Kawasaki in Japan (Kanada et al. 2013). Greenstone analysed India's air and water pollution prevention and control measures (Greenstone et al. 2014). Wu analysed the effectiveness of air pollution control measures in the Beijing-Tianjin-Hebei region of China (Wu et al. 2015). Gauderman argued that air governance can be effectively improved by establishing the association (Gauderman et al. 2015). Gao proposed a control policy to improve China's air pollution by conducting a cost-benefit analysis (Gao et al. 2016). Existing literature indicates that due to the continuous emergence of environmental problems, many governments around the world are focusing on environmental issues and formulating important policies to improve the environment. In the academe, scholars pay increasing attention to the treatment of air pollution and conduct in-depth and comprehensive research on this issue. In the present work, we regard Anhui Province as an example to analyse the present situation and causes of air pollution, explore the temporal and spatial variations in air pollution in the past three years, and establish corresponding solution policies. This study provides a scientific basis for the treatment of environmental and air pollution and offers reliable policy suggestions for the improvement of the quality of the living environment.

CAUSES OF AIR POLLUTION IN ANHUI PROVINCE

Unreasonable energy structure: The energy consumption in Anhui Province continues to increase. As shown in Fig. 1, the total energy consumption in 2015 was 2.5 times greater than that in 2000. In terms of energy consumption, coal is the main energy, and wind, natural gas and other clean energy account for small proportions. This consumption pattern is due to the abundance and low cost of coal resources. The proportion of coal consumption in Anhui Province is higher than the average level of the country. Residents' domestic heating mainly relies on coal burning, which increases the amount of pollutants in the air, including sulphur dioxide and micro particles. The areas with a large number of coal burning boilers are mainly distributed in the industrial and residential locations of the city. The economic growth of Anhui Province depends heavily on the development of raw materials, high energy and heavy industries with extensive processing. The industrial emissions in the area exert an important influence on air pollution.

Accelerating urban infrastructure construction: Cement, steel, electric power, chemical, and other heavily polluting enterprises are distributed in Anhui Province, and most of them need further improvement in structure due to the back-

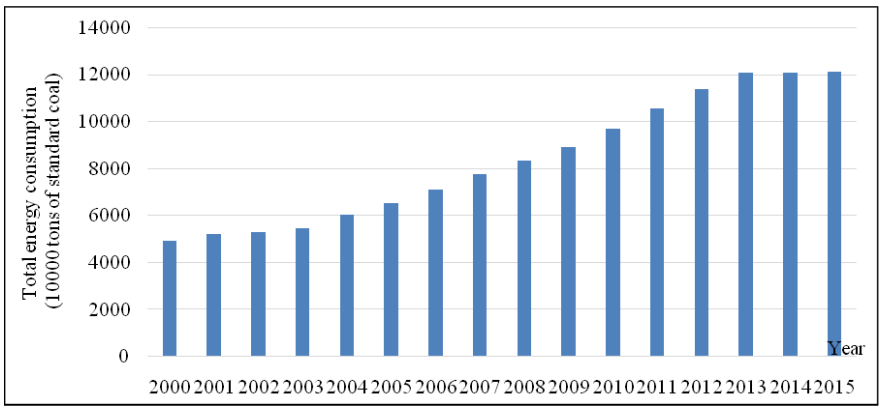

Fig. 1: Total energy consumption of Anhui Province in 2000 and 2015. (Data source: Anhui Province Statistical Yearbook, 2001 to 2016).

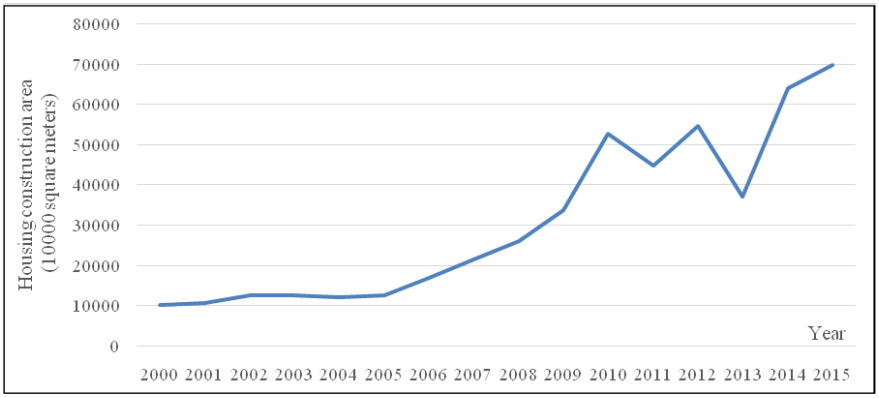

Fig. 2: Housing construction area in Anhui Province in 2000 and 2015. (Data source: Anhui Province Statistical Yearbook, 2001 to 2016).

ward production facilities, high energy consumption, and high pollution emissions. In addition, many coal heating facilities and other types of industrial enterprises remain concentrated in the city centre. With the increase in population in recent years, urban residential areas have continued to expand towards the suburbs. The proximity of residential areas to industrial areas causes function disorders between production and living areas and between industrial and residential areas. Internal and external interactions exert an important influence on air quality in urban areas. In addition, the continuous population growth in Anhui Province has prompted extensive construction of housing buildings, as shown in Fig. 2. Roads and other infrastructure are constructed yearly, and large-scale houses are built around cities. Poor management of the secondary dust pollution caused by building construction, housing demolition and road construction increases the degree of air pollution.

Increasing motor vehicle emissions: The number of motor vehicles in Anhui Province has been increasing (Fig. 3), and this increase leads to an increment in exhaust emissions. Although fuel is of low quality and contains a significant amount of sulphur, many consumers continue to use unqualified gasoline, which causes serious carbon deposition, mechanical wear, and vehicle emission deterioration. Meanwhile, road construction is not proportional to the number of motor vehicles, resulting in low vehicle speed and excessive exhaust emissions. Moreover, unreasonable road designs or constructions cause vehicle congestion. Motor vehicles run at a low speed in cities, and this condition causes the emission index of motor vehicle exhausts to increase continuously. Given the limitation of automobile manufacturing technology, motor vehicles are of poor quality and fail to meet the emission standards. Most motor vehicles are not installed with exhaust purification devices and thus produce large amounts of exhaust.

TEMPORAL AND SPATIAL VARIATION CHARACTERISTICS OF AIR POLLUTION IN ANHUI PROVINCE

Data source and processing: The relevant statistical data used in this work were from the API data of 17 cities in

Anhui Province (Hefei, Hauibei, Bozhou, Suzhou, Bengbu, Fuyang, Huainan, Chuzhou, Liuan, Maanshan, Chaohu, Xuancheng, Wuhu, Tongling, Chizhou, Anqing, and Huangshan) for the last three years. These data are available on the website of Anhui Province Environmental Protection Bureau (http://www.aepb.gov.cn/).

Comparative analysis of air pollution indexes: According to Table 1, the annual average API values of different cities in Anhui Province in 2013 and 2015 ranged from 49.2 to 81.2. The average values in 2013, 2014 and 2015 were 64.8, 73.2 and 70.8, respectively. The values for several industrial cities, such as Hefei, Huaibei, Chuzhou and Anqing, exceeded 70, whereas, the values for Chaohu and Huangshan were low because they are tourist cities with low industrial waste emissions. Wheat and corn are grown in Huaibei, and the practice of straw burning in this area causes air pollution. Anhui Province can be divided into five natural areas according to terrain. The five areas are Huaibei Plain, Jianghuai Hill, Dabie Mountains in west Anhui, Yanjiang Plain and mountainous area in the south Anhui. The three plains are conducive to the spread of pollutants from north to south, and the two mountain areas block the spread. As a result, pollutants are accumulated in central Jianghuai Hill and eastern Jiangnan area, leading to the rise of API values.

Analysis of air quality levels: As indicated in the air quality statistics of Anhui Province in 2015 (Table 2), the number of days with Level I air quality ranged from 14 to 191 in 14 cities of Anhui Province in 2015. These values accounted for 3.8% to 53% of the entire year. The air quality in Maanshan was the worst and that in Huangshan was the best. The number of days with Level II air quality ranged from 164 to 319, accounting for 44.9% to 87.4% of the entire year. The number of days with good air quality reached 262 to 365, accounting for 71.8% to 100.0% of the entire year. The air quality in Maanshan was the worst and that in Huangshan was the best. The number of days with Level III air pollution ranged from 0 to 86; the pollution was the most serious in Hefei. The Level III air pollution in Huainan, Maanshan and Anqing lasted over 60 days. The following four cities suffered from Level V air pollution: Huaibei, Bozhou, Suzhou and Bengbu. These cities are all located in the Huaibei area.

Table 1: Average API values of different cities in Anhui Province in 2013 and 2015.

City	2013	2014	2015
Hefei	73.6	75.4	76.4
Huaibei	70.9	73.1	68.4
Bozhou	65.2	76.5	72.4
Suzhou	63.7	77.8	76.4
Bengbu	67.5	80.5	81.2
Fuyang	68.3	68.7	63.4
Huainan	70.3	82.8	82.8
Chuzhou	75.7	76.4	72.1
Liuan	62.5	76.4	74.5
Maanshan	70.9	78.5	76.3
Chaohu	64.1	63.4	63.1
Xuancheng	66.8	73.7	69.5
Wuhu	58.2	74.2	69.5
Tongling	64.1	76.2	68.2
Chizhou	49.2	59.4	60.2
Anqing	61.0	79.7	74.2
Huangshan	49.9	51.4	54.2

Table 2: Air quality statistics of different cities in Anhui Province in 2015.

	I	II	III1	III2	IV1	IV2	V
Hefei	114	164	86	1	0	0	0
Huaibei	50	278	28	5	2	0	2
Bozhou	17	319	25	3	0	0	1
Suzhou	16	319	24	2	1	0	3
Bengbu	44	259	39	18	3	0	2
Fuyang	85	242	32	6	0	0	0
Huainan	26	263	60	15	1	0	0
Chuzhou	61	247	43	9	4	1	0
Liuan	88	247	22	5	2	1	0
Maanshan	14	248	75	22	3	3	0
Chaohu	93	251	19	2	0	0	0
Xuancheng	46	283	26	9	1	0	0
Wuhu	37	287	29	10	1	1	0
Tongling	19	306	32	7	1	0	0
Chizhou	96	251	16	2	0	0	0
Anqing	41	248	62	13	1	0	0
Huangshan	191	174	0	0	0	0	0

PREVENTION AND CONTROL MEASURES OF AIR POLLUTION

Optimizing the industrial layout in Anhui Province and strengthening governmental management: The number of industrial points in Anhui Province is large, and these points are generally scattered. They comprise heavy and light industries, hence the high degree of air pollution in these areas. On the basis of the present situation of air pollution in Anhui Province, concerned parties should implement measures to optimize the industrial layout. Industrial points should also be concentrated in the suburbs far from urban residential areas and in the downward direction of the dominant wind. In this way, the air pollution caused by the unreasonable layout of urban industries could be effectively addressed. The air quality of a city is closely related to the policy management of the functional department. To strengthen the local governments' consciousness about environmental responsibility, strict air and environmental protection laws and regulations should be introduced, and a

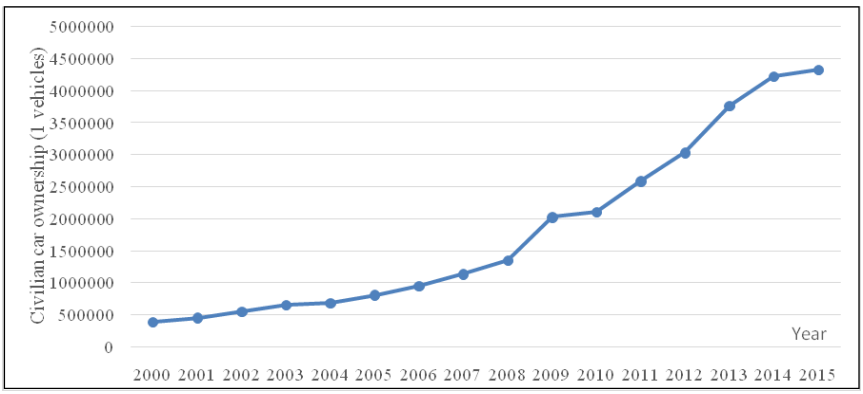

Fig. 3: Numbers of civilian motor vehicles in Anhui Province in 2000 and 2015. (Data source: Anhui Province Statistical Yearbook, 2001 to 2016).

system of rewards and punishments must be established to prevent illegal behaviours that aggravate air pollution. An ultra-low emission policy must also be implemented. At present, the mainstream ultra-low emission technologies include shoot removal, desulphurization and dust removal. These technologies can reduce energy consumption, reduce pollution emissions and improve production efficiency. Related departments should accelerate research work, stay focused on technical innovations in the field, and design a comprehensive and solid technical route to ensure the effect of ultra-low emissions and reduce the effect of industrial pollution emissions and winter coal-fired heating on air pollution in cities. Local governments should also strictly implement pollution monitoring and mandatorily require heavily polluting enterprises that do not meet entry requirements to move out. At the same time, the online monitoring of enterprises' discharge must be strengthened, and undesirable behaviours, such as poor management, false data and illegal exhaust emissions, must be eliminated.

Improving air pollution treatment policies and formulating strict emission standards: Air pollution control strategies should be adjusted according to the actual situation of Anhui Province. The focus of air pollution treatment should be on the control of the total amount of pollutants and on environmental quality management and risk control. Thus, the government should consider environmental quality and risk control when formulating relevant policies. In practice, control should be shifted from primary pollution to both primary and secondary pollution. Moreover, the damage caused by secondary pollution should be highlighted, and a policy system that can effectively control and reduce secondary pollution should be established. The economic policy regarding air pollution reduction should be improved, and economic policies suitable for the development of Anhui Province should be explored to standardize the policy institutions of air pollution treatment. For heavily polluting enterprises, the government and related departments should force them to move to the suburbs to reduce the pressure on the urban air environment. Environmental protection agencies should implement means of rewards and punishments during the development of the emission standard of air pollutants to encourage those abiding by the standard and to punish those that fail to meet the standard. In this way, the emission standard of enterprises would be strictly regulated, and they would be forced to take measures to meet the standard.

Improving urban infrastructure planning and strengthening the emission treatment of motor vehicle exhaust: In terms of urban planning policies, Anhui Province should further optimize the urban space layout and improve the major functions of cities according to the route of sustainable development. In terms of industrial planning policies, an overall plan and a comprehensive arrangement for the strategic layout of industrial development should be established. Specifically, industrial clusters should be far from the city centre, and industrial development and air pollution control policies must be implemented simultaneously to achieve the goal required by function area planning. In terms of heat supply planning policies, Anhui Province should formulate a policy program that combines various heating means with cogeneration and natural gas as the primary sources and with electricity, geothermal energy, and other high-quality energy as the auxiliary sources as soon as possible. It should also actively encourage coal-to-gas activities. Policies that control motor vehicle exhaust pollution should be immediately formulated to regulate motor vehicle exhaust emissions and finally control motor vehicle pollution. In addition, legal

documents should be drafted to strictly regulate the annual inspection of motor vehicle exhaust, vehicle examination on the road, and punishment on excessive exhaust to control motor vehicle exhaust pollution from the source.

Strengthening the input in air pollution treatment and improving the technical content: The cost of air pollution treatment should be included in the annual budget to ensure the source of funds for air pollution control. The development of enterprises should be in accordance with national air pollution emission standards to ensure that all pollution emissions meet the prescribed standards. For the excessive pollution problem, the government should strictly punish enterprises with a fine and spend these fines on air pollution control. In addition, the air quality evaluation method should be improved further, and corresponding treatment policies and measures should be developed. In the control of air pollution, the key is to speed up the development of clean energy, investigate new technologies, and increase the R&D on purification technologies for vehicles and treatment technologies for the emission of pollutants by industrial production facilities.

SUMMARY AND CONCLUSIONS

Air pollution causes a decline in air quality, the greenhouse effect, acid rain, fog and other serious conditions. Consequently, it poses a threat to human life. Population growth, industry concentration, traffic congestion and energy consumption contribute to the increasing severity of air pollution. To further analyse the quality of the air environment and make further adjustments to air pollution control policies, this paper regarded Anhui Province in China as an example and analysed the specific causes of air pollution. It also performed a comparative analysis of API data and graded the air quality in different cities in 2015 on the basis of the API data of Anhui Province from 2013 to 2015. The research results showed that the main causes of air pollution in Anhui Province from 2013 to 2015 were unreasonable energy structure, accelerated urban infrastructure construction and increasing motor vehicle emissions. Air pollution showed an overall fluctuating growth. Urban air pollution in northern Anhui Province was more serious than that in southern Anhui Province. It also examined the temporal and spatial variation characteristics of air pollution based on urban air pollution data. Policy suggestions were provided for the scientific development of air pollution treatment measures, effective implementation of air pollution management and earnest improvement of the air pollution status. Further research can be conducted to extend the time span of air quality data and make up for the deviation caused by insufficient data by acquiring meteorological data through multiple channels and websites and by exploring the important factors that affect the change in air quality.

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