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A study of spatial-temporal evolution of China's urban environmental pollution

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ABSTRACT

The problem of environmental pollution brought by the rapid economic development in China caught increasingly great attention of the world. The wide-range of hazy weather since 2013 has shown the seriousness of problem of its environmental pollution. This paper, using the Synthetical Index Method to build the urban "Pollution Index" and "Urban Economy-Pollution Index", makes the analysis of the environmental pollution and evolvement features of the 30 major Chinese cities. According to the results, during 2005-2012, the pollutants discharge per unit economic output in its 30 cities showed by and large a downward trend. Urban pollution in this country underwent a development process from concentrating in a handful of cities to scattering to more extensive space. Of these cities, 8 currently fell into the category of "Severity", with a large amount of discharge of urban pollutants, being in the state of extensive growth. In terms of types of pollutants causing urban pollution, there are differences between each city.

KEYWORDS

Pollution index; Urban economy-pollution index; Atmospheric pollution; Water pollution; Solid pollution; Temporal and spatial evolution.

INTRODUCTION

The wide-range and prolonged hazy weather since 2013 has once again made prominent the problem of environmental pollution in China's urban areas. Haze belongs, in physical form, to the atmospheric pollution. In fact, the problem of environmental pollution in Chinese cities is not limited to the atmospheric pollution, and their water pollution and solid wastes pollution are also serious. Obviously, over 30 years of continuous and rapid economic growth in China was garnered at the sacrifice of its urban environment, which has been on the gradual deterioration. The extensive haze emergence is a strong signal indicating that the problem of environmental pollution in Chinese cities in recent years has become more serious than ever before.

Urban environmental pollution was not caused by pollutants discharge of the city itself, sometimes; for instance, in hydrological terms, cities located at the upper reaches will influence those at the lower reaches and general atmospheric circulation will function as conveying air pollutants. However, the environmental pollution of a city is, to a great extent, closely associated with its own pollutants discharge. In light of this, the following three aspects of research are conducted in this paper: (1) research on the formation mechanisms and distribution patterns of urban environmental pollution. Querol X et al studied the sources and formation of air pollution in European cities and differences between them[1]. Parkhurst W J et al analyzed the historical data on air pollution in southeastern United States, pointing out the general patterns of formation of their pollutants[2]. Lv Pu et al studied the meteorological conditions and pollutant sources formed by the hazy pollution in 8 cities including Beijing[3]. (2) Analysis of the status quo and causes of formation of urban environmental pollution in China. AnWeishu recently analyzed the trends and hazards of environmental pollution in Chinese cities and proposed relevant policy suggestions for controlling urban environmental pollution[4]. Wang Wei also analyzed the causes for air pollution, water resource pollution and urban garbage pollution in Chinese cities and proposed measures for preventing and controlling environmental pollution[5]. (3) Research on the relevancy of urban environmental pollution to urban economic development. Song Tao et al used the environment-economic simple theoretic model to analyze the long-term and short-term relationship between environmental pollution and economic growth; they also made the empirical study of long-term and short-term relationship between per capita CO_2 emissions and per capita GDP during 1960-2000[6]. Liu Chi and ZhongShuiying made the quantitative analyses using the Wuhan Urban Economic Development Comprehensive Index and emissions of liquid wastes, waste gas and solid wastes, respectively, and arrived at corresponding patterns of historical evolvement[7]. These studies provided reference in ideological and methodological terms for analyzing the problem of environmental pollution in Chinese cities.

This paper analyzes the following issues, using the 2005-2012 statistical data on environmental pollution in major Chinese cities: within these 7 years, was the urban environmental pollution in China more concentrated in part of its cities or did it show a decentralized trend after all? Increases in pollutants discharge are inseparable from economic aggregates. Therefore, in terms of level of economic development, which cities grew in an extensive manner at the cost of pollution? Pollution includes not only the atmospheric pollution, but also water and solid wastes pollution, although the former is of more dominant character, more direct and more socially negative. Which of the 3 kinds of pollution is the biggest challenge facing the Chinese urban environment? The major cities mentioned in this paper refer to the four municipalities directly under the central Chinese government and 26 provincial cities, excluding Lhasa, capital city of Tibet whose data are unavailable.

METHODOLOGIES

Synthetical index method

The Synthetical Index Method (SIM) is a feasible method by which to gauge the state of environmental pollution in a city and make the inter-city sorting. And this method is widely used in the study of ranking of urban competitiveness and urban innovation ability, which is suited to the comprehensive ranking with multi-dimensions and multi-assessment objectives. Its advantages lie in the fact that it cannot only objectively reflect the holistic state of evaluated objects, but also embody the importance of a certain dimension relative to other dimensions through the size of weights. This paper uses SIM to calculate the "Pollution Index" and "Urban Economy-Pollution Index" of Chinese cities, in order to do the ranking of holistic state of environmental pollution and degree of pollutants discharge per unit economic output of the 30 Chinese cities. In this research, the evaluated objects are the 30 cities, and the 3 dimensions are water pollution, atmospheric pollution and solid wastes pollution. The idea of building of the comprehensive index is, firstly, making the data normalization processing of the 3 types of pollutants to remove the dimensional differences between them; secondly, giving corresponding weights to the 3 types of pollution based on their economic and social influence, so as to finally arrive at the comprehensive index. The computational formula is as below:
(1) Computational formula of the "Pollution Index" (P_i):

$$P_i = \frac{L_i + 2 \times G_i + S_i}{4} = \frac{\left(l_i / \sum l_i\right) \times 100\% + 2 \times \left(g_i / \sum g_i\right) \times 100\% + \left(s_i / \sum s_i\right) \times 100\%}{4} \quad (1)$$

In which, P_i is the "Pollution Index" of city i; L_i is the water "Pollution Index" of city i; $G_i$is the atmospheric "Pollution Index" of city i; S_i is the solid wastes "Pollution Index" of city i; l_i is the amount of liquid wastes discharge of city i; g_i is the amount of waste gas discharge of city i; s_i is the amount of solid wastes discharge of city i. The data range of i is [1, 30].

(2) Computational formula of "Urban Economy-Pollution Index" (I_i):

$$I_i = \frac{P_i}{Y_i} = \frac{\left[\left(l_i / \sum l_i\right) \times 100\% + 2 \times \left(g_i / \sum g_i\right) \times 100\% + \left(s_i / \sum s_i\right) \times 100\%\right] / 4}{\left(y_i / \sum y_i\right) \times 100\%} \quad (2)$$

In which, I_i is the "Urban Economy-Pollution Index"of city i; P_i is the "Pollution Index" of city i; Y_i is the economic index of city i; y_i is the economic aggregate of city i. The data range of i is [1, 30].

Spatial gini coefficient

Spatial Ginicoefficient is a method used to gauge the degree of spatial agglomeration of economic activities. The issue of spatial agglomeration received attention of economists and geographers a long time ago, such as, A.Weber and A. Marshall, who paid high attention to the issue of industrial clustering during the early 1900s. After the 1980s, many well-known economists began to study the issue of spatial agglomeration of economic activities. And the new economic geography schoolrepresented by Paul R. Krugman paid special attention to the issue of spatial agglomeration. When studying the issue of spatial agglomeration, economists and geographers proposed a series of methods of calculation of degree of agglomeration, such as, coefficient of standard deviation, concentration index, concentration ratio and spatial Gini coefficient. And spatialGini coefficient is the most representative, which was first proposed by Paul R. Krugman, the American economist in 1991. He used this method to compute the level of spatial agglomeration of 106 manufacturing industries in the U.S. in 1991. Afterwards, this method was widely used in the measurement of other issues of spatial agglomeration. This paper uses this method to calculate the degree of concentration of urban pollution in China, computing the spatial Gini coefficient of two points-in-time, respectively so as to find out whether Chinese urban pollution becomes more centralized or scattered within this period. Its computation formula is as below:

$$G_i = \frac{1}{2n^2\overline{S}} \sum_{j=1}^{n} \sum_{m=1}^{n} \left| S_j^i - S_m^i \right| \quad \textbf{(3)}$$

In the formula, G_i is the spatial Gini coefficient of urban environmental pollution type i; i is water pollution, atmospheric pollution, solid wastes pollution or the integration of these three types of pollution; S_j^i is the share of discharge amount of pollution type i of city j in the country; S_m^i is the share of discharge amount of pollution type i of city m in the country; n is the number of cities; $\overline{S}$ is the national average share of discharge amount of pollution type i. SpatialGini coefficient varies within 0 – 1, and the more it is close to zero, the more even the spatial distribution of pollution type i is; the more it is close to 1, the more centralized the spatial distribution of pollution type i is.

Location quotient

Location quotient, also known as regional specialization rate, is an analytic method frequently used in the study of regional and urban science. It was initially used to reflect the level of specialization of a specific industrial sector in a certain region or city relative to that of this national industrial sector, by which to discover the industrial sector with the comparative advantage in this region. Its principle is, assumed that there are several sub-regions within a large region, of which a certain sub-region has an industry with a relatively high degree of concentration compared with the same industry in other sub-regions, we may come to the conclusion that this sub-region has the comparative advantage in this industry within the entire large region and it may provide products or services to other sub-regions. This paper, using the method of location quotient for analysis, may discover that relative to the national average level, which aspects of the urban pollution a certain city highlights, which type or types of pollution it suffers more seriously. The computation formula is as below:

$$CL_i = \frac{L_i / B_i}{L / E} \quad \textbf{(4)}$$

$$CG_i = \frac{G_i / E_i}{G / E} \quad \textbf{(5)}$$

$$CS_i = \frac{S_i / B_i}{S / E} \quad \textbf{(6)}$$

In which, CL_i, CG_i, and CS_i are the location quotients of water pollution, atmospheric pollution and solid wastes pollution of city i, respectively; the data range of i is [1, 30]; L_i, G_i and $S_i$are the discharge amounts of liquid waste, waste gas and solid wastes of city i, respectively; E_i is the total discharge amount of pollutants of city i; L, G and S are the discharge amounts of total liquid waste, total waste gas and total solid wastes of the 30 cities in China, respectively; E is the total discharge amount of pollutants of the 30 cities in China. If $CL_i>1$, it indicates that the liquid wastes discharge of city i exceeds the national average level of discharge of the 30 cities in the country, and the same is true with CG and CS.

RESULTSAND DISCUSSIONS

Features of temporal evolution of China's Urban environmental pollution

Discharge of major pollutants in Chinese cities went up and down in recent years. Statistics show that there was a relatively fast rise in the discharge of liquid wastes, a decline in the discharge of waste gas and a great increase in the discharge of solid wastes. In 2005, discharge of liquid wastes of the 30 cities in China totaled 5.39 billion tons, and in 2012, it reached to 17.67 billion tons. In 2005, discharge of SO_2, smoke and dusts of the 30 cities in the country totaled 6.48 million tons, and in 2012, it lowered to 5.11 million tons. During this same period, discharge of solid wastes (the output of general industrial solid wastes minus the usage amount of the same) rose from 43.83 million tons to 64.34 million tons.

In the evaluation of the features of temporal evolution of China's urban environmental pollution, we just cannot look at the changes in the total amount of pollutants discharge only; we should instead make the objective evaluation based on the changes in urban population and economy of scale. In 2005, the total population in the 30 major Chinese cities was 233 million with the gross regional domestic product totaling RMB7.41 trillion (current price). In 2012, the total population of the 30 cities increased to 255 million with the gross regional domestic product totaling RMB21.47 trillion (current price). According to formulas (1) and (2), we built the "Urban Economy-Pollution Index" to gauge the state of China's urban environmental pollution, in which the urban economic aggregate is calculated based on the 2005 constant price. The results indicate that during 2005-2012, with the upgrading of urban industrial structure and strengthening of urban pollution control, the pollutants discharge per unit economic output of the 30 Chinese cities showed a downward trend. If the pollutants discharge per unit gross regional domestic product of the 30 cities is 100 in 2005, then it reduced to 76in 2012.

It can be noticed from the analysis of each city which cities eased up and which were more serious in environmental pollution. It can also be discovered from the computation of "Urban Economy-Pollution Index" of the 30 cities that relative to the urban economic aggregate, 14 of them eased up while 16 became serious in environmental pollution. Of the 14 cities with mitigated urban environmental pollution, 7 cities werestill more serious in urban pollution than the national urban average level in 2012, which were mainly the cities in the central and western regions, such as, Guiyang, Xining, Chongqing, Zhengzhou and Taiyuan. Of the 16 cities with deteriorating urban environmental pollution, only 5 were still more serious in urban pollution than the national urban average level in 2012, including Harbin in the northeast, and Urumchi, Lanzhou, Huhhot and Kunming in the west of China.

Features of spatial evolution of China's Urban environmental pollution

The population and economic output in Chinese urban areas are highly concentrated in a handful of megacities, such as, Shanghai, Beijing, Guangzhou, Shenzhen, Tianjin and Chongqing. In 2005 and 2012, the population of these 6 cities accounted for equally 32.5% of the total population in the 30 cities in the country while the total gross regional domestic product of them accounted for 44% and 42% of the total of that of the 30 cities in the country, respectively. Under the backdrop of relatively stable population and economic output, was the state of China's urban environmental pollution more centralized or dispersed in terms of spatial distribution? We shall use formula (1) to calculate the normalization "Pollution Index" of the 30 cities, and then, according to formula (3), we shall calculate the spatial Gini coefficient for urban pollution of the 30 cities. If the coefficient becomes larger, it indicates that urban pollution is more concentrated; if it becomes smaller, it shows that urban pollution is dispersed.

The results of calculation show that in 2005, the spatial Gini coefficient for urban pollution of the Chinese cities was 0.42 and it lowered to 0.36 in 2012. That the spatial Gini coefficient becomes small indicates China's urban pollution is more dispersed in spatial terms. It is thus clear that with the accelerated progress of industrialization, Chinese urban pollution was dispersed to more cities, and the urban pollution was a general phenomenon and was not concentrated in a handful of megacities.

In terms of direction of diffusion of urban pollution, during 2005-2012, China's urban pollution showed the trend of changes diffusing from cities in the east central region to those in the northeast, north and west of China. In 2005, the "Pollution Index"of a few cities in the eastcentral regions, such as, Shanghai, Nanjing, Hangzhou, Zhengzhou, Taiyuan and Shijiazhuang ranked at the forefront of the country. In 2012, except for Shanghai with a slight increase, all other cities showed a significant decrease in the "Pollution Index". At the same time, there was a significant rise in it in Shenyang, Changchun and Harbin in the northeast, Beijing, Tianjin and Jinan in the north, Kunming, Yinchuan, Lanzhou and Huhhot in the west of China. And the "Pollution Index" of Kunming rose from 5.1 to 8.9, ranking first in the amount of increase in the country. Kunming, known as the "city of perpetual spring" with the beautiful environment is now being threatened by environmental pollution, of which we must be alert.

Classification by features of China's Urban environmental pollution

Given that the 30 major Chinese cities are distributed in this vast land, in order to formulate differentiated policies for controlling urban environmental pollution, it is necessary to classify the 30 cities based on the features of environmental pollution. It is generally acknowledged that those with large amounts of pollutants discharge are the ones with a high "Pollution Index" and cities showing an extensive growth are the ones with a high "Urban Economy-Pollution Index", which are worth of our attention. In light of this, we use the "Pollution Index" and "Urban Economy-Pollution Index" as the vertical and horizontal coordinates, respectively, and according to the 2012 scoring, we draw the 30 cities on a two-dimensional coordinate axis, from which we can directly see the features of environmental pollution in each city.

With the average of 3.3 of the 30 cities' "Pollution Index" and the average of 100 of their "Urban Economy-Pollution Index" as the boundary line, we may divide the 30 cities into 4 quadrants, and the cities distributed in the 4 quadrants represent different categories.

(1) Cities in the 1st quadrant: "Severity" type of city. Cities falling into this category are mainly distributed in the north and southwest of China, including Shijiazhuang, Taiyuan, Zhengzhou, Huhhot, Nanjing, Chongqing, Guiyang and Kunming. These cities should currently be given top priority in fighting against China's urban environmental pollution; they are characterized by large pollutants discharge and heavy urban environmental pollution due to extensive economic growth.

(2) Cities in the 2nd quadrant: "Control" type of city. Cities falling into this type include three municipalities directly under the Chinese central government, such as, Shanghai, Beijing and Tianjin. These three cities are developed in the service industry and no longer develop high-pollution industries, and they have strengthened efforts to combat environmental pollution. Therefore, they are low in "Urban Economy-Pollution Index". However, due to large size of these cities, their aggregate pollutants discharge is huge, and it is necessary for them to strengthen management and control of pollutants discharge.

(3) Cities in the 3rd quadrant: "Safety" type of city. Cities falling into this category are mainly those in the central-east region, including Hefei, Nanchang, Wuhan, Changsha, Hangzhou, Fuzhou, Guangzhou, Haikou, Jinan, Nanning, Shenyang, Changchun, Chengdu and Xi'an. The total pollutants discharge of these cities is not large, and the discharge intensity of them is not either, in terms of their economic size, and they therefore belong to "Safety" type of city.

(4) Cities in the 4th quadrant: "Improved" type of city. Cities of this type are mainly distributed in China's northwest region, including Lanzhou, Xining, Yinchuan, Urumchi and Harbin. The total pollutants discharge of these few cities is not large, but they belong to those in the extensive growth

mode, relative to their size of economy. Their "Urban Economy-Pollution Index" is above the national average and they should attach importance to the issue of prevention and control of urban environmental pollution as quickly as possible.

Classification by types of China's Urban environmental pollution

The purpose of calculation of urban "Pollution Index" is to reflect the overall situation of urban pollution. On the other hand, only when we understand pollution sources that cause urban environmental pollution, can we engage in targeted control. Additionally, the "Pollution Index" of some cities is not high and their environmental pollution is generally not serious, either. However, in reality, relatively big problems may exist in a certain type of environmental pollution, which therefore need special attention. Hence, we used formulas (4), (5) and (6) to calculate the location quotients of water pollution, atmospheric pollution and solid wastespollution, respectively of the 30 Chinese cities, thus arriving at the pollution intensity of each type of pollution in each of them. And we also made the collection and classification accordingly. If the location quotient of a certain type of environmental pollution in a city is greater than 1, then it indicates that this type of pollution of this city is more serious than the overall situation of this same type of pollution of the 30 cities. The results of classification is shown in the below figure.

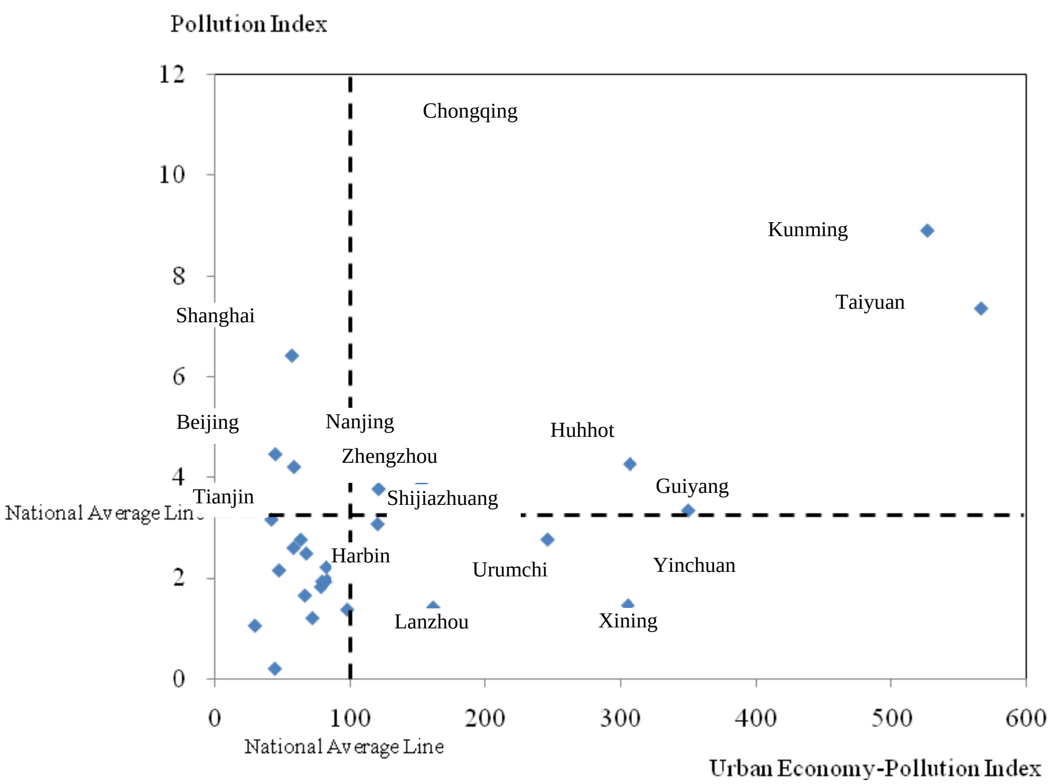

Figure 1 : Chinese cities distribution by environmental pollution features

Based on the results of calculation of location quotients of three types of pollutants in the 30 cities, these 30 cities may be divided into the following 4 categories:

(1) Urban agglomeration 1: only the location quotient of water pollution is greater than 1. Cities falling into this category are mainly those megacities in the east-central region, including Beijing, Shanghai,

Hangzhou, Guangzhou, Haikou, Changsha, Nanchang and Chengdu. Their liquid wastes discharge is higher than the overall level of the 30 cities in the country, and the location quotient of water pollution in Haikou is 3.2, and it is 2.7 in Guangzhou, and 2.4 and 2.3 in Changsha and Chengdu, respectively. These four cities are most in need of attaching importance to water pollution

(2) Urban agglomeration 2: only their location quotient of atmospheric pollution is greater than 1. Cities falling into this category are highly concentrated in the northeast, north and northwest of China, including Shenyang, Changchun, Harbin, Jinan, Shijiazhuang, Lanzhou, Yinchuan, Xining, Urumchi and Chongqing. And their atmospheric pollutants discharge is higher than the overall level of discharge of the 30 cities in the country. In addition, Xining's location quotient of atmospheric pollution reached 1.8, and it is 1.6 for Harbin, Lanzhou and Jinan. These four cities are most in need of attaching importance to atmospheric pollution.

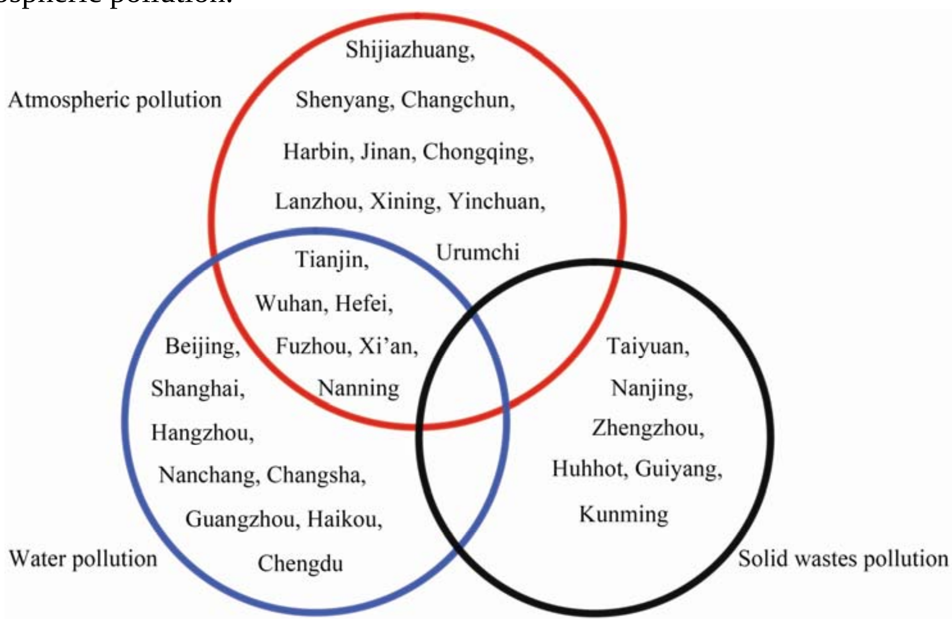

Figure 2 : Classification of Chinese cities by types of environmental pollution

(3) Urban agglomeration 3: location quotients of both water and atmospheric pollution are greater than 1. Cities of this type include Tianjin, Fuzhou, Wuhan, Nanning and Xi'an. Water and atmospheric pollution of these cities are both higher than the overall level of the 30 cities in the country, and their environmental pollution is facing pressure from both aspects.

(4) Urban agglomeration 4: only the location quotient of solid wastes is greater than 1. Cities of this type are a few and concentrated in the north and southwest regions of China, including Taiyuan, Zhengzhou, Huhhot, Nanjing, Guiyang and Kunming. Solid wastes discharge of these cities is higher than the overall level of the 30 cities in the country. Also, the location quotients of solid wastes pollution in Kunming and Guiyang reached 2.9 and 2.1, respectively; they reached 2.7 and 2.6 in Taiyuan and Huhhot, respectively. Solid wastes pollution is the fundamental cause for the worsening environmental pollution of these cities, and is the area of improvement in urban environment.

CONCLUSIONS

Although atmospheric pollution is the area most concerned in urban environmental pollution, water and solid wastes pollution should not be neglected. Through building and calculating across the board the "Pollution Index" and "Urban Economy-Pollution Index", this paper reveals the state of environmental pollution and evolvement features of the 30 major Chinese cities.

In time terms, during 2005-2012, pollutants discharge per unit economic output of the 30 Chinese cities showed a downward trend. If the pollutants discharge per unit gross regional domestic product of the 30 cities in 2005 is regarded as 100, the results of calculation showed that this figure lowered to 76in 2012. The analysis of the 30 cities showed that relative to their urban economic aggregates, the environmental pollution in 14 of them eased up while it was deteriorating in 16 others.

In spatial terms, China's urban pollution showed a development trend of diffusing to a wider space. During 2005-2012, the spatial Gini coefficient for China's urban "Pollution Index" became smaller, indicating that urban pollution was more dispersed in spatial terms. And in terms of direction of diffusion of urban pollution, it showed a trend of changes diffusing from cities in the east-central region to those in the northeast, north and northwest of China. And Kunming's "Pollution Index" ranked first among the 30 cities in terms of increase in it.

In terms of comprehensive analysis of the degree of urban environmental pollution, 8 cities including Shijiazhuang are currently the cities of "Severity" type with large amounts of pollutants discharge, and they are in the extensive growth mode; pollutants discharge in Shanghai, Beijing and Tianjin is relatively large, falling into the "Control" type; 5 cities including Lanzhou belong to the "Improved" type, and although their total pollutants discharge is not large, they fall into the category of extensive growth, relative to the size of their economic output; 14 cities including Hefei belong currently to the "Safety" type.

In terms of the three types of urban environmental pollutants discharge, environmental pollution in the 30 Chinese cities can be divided into four categories: (1) only water pollution is above the national average, including 8 cities, such as Beijing. In structural terms, they are mainly the megacities in the east-central region; (2) only atmospheric pollution is above the national average, including 10 cities, such as Shenyang, which are highly concentrated in the northeast, north and northwest of China; (3) both water and atmospheric pollution are above the national average, including 6 cities, such as Tianjin; and, (4) only solid wastes pollution is above the national average, including 6 cities, such as Taiyuan, which are concentrated in the north and southwest of China.

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