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Analysis of the Driving Factors of PM2.5 in Henan Province Based on Grey Correlation Model

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Abstract

During the winter, the haze weather in Henan Province frequently appears, the main pollutant that causes the haze weather is PM2.5. This article is to explore the economic and social influencing factors of PM2.5 in Henan Province. According to the geographical distribution of each prefecture-level city in Henan Province, five cities (Zhengzhou, Luoyang, Anyang, Shangqiu, Xinyang) are selected as the research objects, and the economic and social driving factors of the annual average concentration of PM2.5 in each city is analyzed based on the gray correlation model. This article founds that although there are regional differences in the distribution of PM2.5 concentration in Henan Province, the PM2.5 concentration of the five selected cities is closely related to industrial structure, urbanization and energy consumption, is unrelated to the number of civilian vehicles and traffic. Therefore, Henan Province's next air pollution prevention measures should focus on the upgrading of industrial structure and urbanization.

Keywords

PM2.5, Henan Province; Social and economic driving factors; Grey Correlation Model.

1. INTRODUCTION

With the advent of winter, haze weather appears frequently, seriously affecting people's lives and work. Haze is a general expression of the excessive content of various suspended particulate matter (PM) in the atmosphere. PM2.5 is rich in toxic and harmful substances, and has a long residence time in the atmosphere and transportation distance because of its small particle size. It is far more harmful to human health and the quality of the atmospheric environment. Since 2013, the haze weather has received widespread attention, and PM2.5 has once become a "hot word". Many cities in China have begun to establish air quality monitoring stations, and analysis of the driving factors of PM2.5 has also became a research hotspot for scholars in various related fields.

From a nationwide perspective, the cities with poor air quality are mainly located in the central and eastern regions, and the common feature of these cities is dense population and rapid industrialization. Henan Province is a populous province located in the hinterland of the Central Plains. Its industrialization started relatively late, but it has developed rapidly in recent years. Among the 74 cities monitored with the new standards in 2017, Zhengzhou's air quality ranked ninth from the bottom, and the main pollutant was PM2.5. According to the monthly national urban air quality report released by the Ministry of Ecology and Environment, in the 12 months of 2018, Zhengzhou, the capital of Henan Province, ranked in the bottom ten of the 169 reported cities twice. Jiaozuo, Pingdingshan and Kaifeng have 3 times, and Anyang ranked as many as 10 times in the bottom ten of the monthly ranking. Although the government has adopted various measures for control and governance, the air quality in Henan Province is still not optimistic. Therefore, analyzing the economic and social driving factors of the main air

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pollutant PM2.5 in Henan Province may be helpful to judge the general direction of air pollution prevention, and to introduce effective measures, policies and regulations.

This article is mainly divided into five parts. The first part is the introduction, briefly introducing the research background and significance. The second part is a literature review, sorting out the research on the causes and influencing factors of PM2.5. The third part is the current situation and distribution of PM2.5 in Henan Province. The fourth part is index data and research methods, briefly introducing the establishment of the index system and the realization process of the grey relational analysis method. The fifth part is the results and recommendations.

2. LITERATURE REVIEW

Since the country began to pay attention to the air pollutant PM2.5 in 2013, a large number of relevant studies have begun to emerge. Initially, in order to figure out the source of PM2.5, scholars mainly found its pollution source through atmospheric analysis. Then the scholars began to analyze the socio-economic background of PM2.5. Due to the different economic and social backgrounds in different regions, many scholars have conducted spatial distribution analysis to explore prevention and control measures tailored to local conditions.

From the results of atmospheric composition analysis, the sources of PM2.5 are mainly produced by human activities, which can be divided into primary sources and secondary formations. Primary sources include industrial dust, motor vehicle exhaust particles, road dust, construction dust, kitchen smoke Etc.; secondary formation refers to the secondary fine particulate matter produced by various chemical and physical processes of gaseous pollutants discharged into the atmosphere (such as sulfur dioxide, nitrogen oxide, ammonia, etc.) in the atmosphere [1] [2]. A large amount of pollutant gas emitted by automobile exhaust and coal combustion can produce secondary PM2.5 through gas particle conversion. In summer with strong sunlight, the proportion of PM2.5 formed by secondary sources can reach 50%-90% [3].

The causes of haze weather include both natural factors and socio-economic factors. Natural factors are mainly unfavorable weather conditions that cause continuous accumulation of pollutants and difficult to spread. Socio-economic factors are mainly energy consumption structure, industrial waste gas, motor vehicle ownership, and urbanization development [4]. Specifically, the energy consumption structure dominated by high coal consumption, the industrial structure with a relatively large proportion of industry, the transportation structure with a large increase in the number of motor vehicles, and the building dust during the urbanization process are the main reasons for the increasingly serious smog [5].

Among them, the size of the city and the level of economic development both have a positive impact on urban smog [6]. The development of urbanization directly leads to an increase in population density, and the probability of haze weather also increases [7]. Liu et al. [8] found that across the country, a 1% increase in urbanization resulted in a 0.029% increase in the concentration of haze pollution. In high-emission areas, 1% increase in urbanization resulted in 0.121% increase in the concentration of haze pollution. At the same time, Leng et al. [9] found that industrial structure and haze pollution are also positively correlated, and the impact of urbanization level and industrial structure on haze pollution will add up to each other. Li et al. [10] found that energy consumption structure has a great influence on air pollutants through analysis. Wu et al. [11] found that the number of motor vehicles has a positive impact on haze pollution.

It can be seen that scholars basically agree that the formation of PM2.5 is mainly related to factors such as industrial structure, urban development, energy consumption structure, and transportation structure. However, the contribution of each factor is different in different regions, so scholars have also started to Research on key polluted areas, especially the literature

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on the causes of haze in the Beijing-Tianjin-Hebei region. Zhao et al. [12] believe that the coal-based energy structure and the heavy chemical industry-based industrial structure are the determinants of air pollution in the Beijing-Tianjin wing, and high energy consumption and high pollution emissions are the root causes of haze weather. In addition, according to the calculations of the Ministry of Environmental Protection and other institutions, the first source of pollution in Beijing is motor vehicles, the second is coal burning, the petrochemical industry in Tianjin is the main source of industrial pollution, and the main source of industrial pollution in Hebei is steel and cement [13]. Ma et al. [14] found that the haze pollution area has obvious characteristics, the central and western regions are due to the unreasonable energy structure, and the eastern part is due to traffic congestion and other reasons.

Because environmental pollution has strong externalities and non-exclusiveness, especially the air pollutant PM2.5 can be transmitted over long distances, the study of its spatial spillover effects has become a new research direction. This kind of literature mostly uses spatial econometric analysis methods. Ma and Zhang [15] found that the distribution of PM2.5 in China has a significant positive spatial correlation, and believe that the spillover effect of pollution is mainly due to industrial transfer, and the areas adjacent to the Beijing-Tianjin wing and the Yangtze River Delta have undertaken some polluting industries. Ren and Guo [16] also found that there is a significant positive spatial autocorrelation of smog pollution in the Yangtze River Economic Belt, and that 1% increase in PM2.5 in neighboring provinces and cities will increase the PM2.5 in the province by 0.61 %.

Regarding analysis methods, most of the aforementioned documents use panel data for quantitative analysis, but quantitative analysis requires relatively high data, and it is difficult to achieve the expected results. In comparison, the gray correlation analysis method has fewer data requirements, and The calculation is simple. He et al. [17], Li and Wang [18]analyzed the influencing factors of PM2.5 concentration in Jiangsu Province and the Beijing-Tianjin-Hebei region based on the gray correlation model. The influencing factor system includes air quality indicators, meteorological factors, and PM2.5. A comprehensive analysis will be conducted on the sources of pollutants, urbanization and social industries. Lu et al. [19] conducted a gray correlation analysis of PM2.5 and various influencing factors based on China's PM2.5 concentration data from 1998 to 2014, and found that meteorological factors, industrial structure, exhaust gas emissions, urban greening and other factors are related to PM2.5 Concentrations all show a high correlation.

There are few literature on the research of air pollutants in Henan Province, and most of the researches are on source analysis of PM2.5. Cao [20] Henan Province PM2.5 and PM10, carbon dioxide, and nitrogen dioxide all show a significant correlation, indicating that pollution is mainly caused by coal combustion and motor vehicle exhaust. Wang [21] believe that air pollutants in the surrounding areas of Henan Province will be transmitted to Henan, and the contribution of surrounding provinces reaches 28%, of which Shanxi Province contributes 9% to the western part of Henan. Resident sources, industrial sources and motor vehicle emissions are the main sources of PM2.5 concentration in Henan Province.

Through combing the literature, it is found that there are very few studies on the social and economic factors behind PM2.5 in Henan Province, and because the formation of PM2.5 is a complex gray system, this article intends to use the gray correlation analysis method to explore the social and economic influencing factors related to PM2.5 in Henan Province.

3. DESCRIPTIVE ANALYSIS

According to the "Report on the State of the Environment in Henan Province in 2017", in accordance with the fine particulate matter (PM2.5), inhalable particulate matter (PM10), sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone in the "Environmental Air Quality

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Standard" (GB3095-2012) The factor evaluates the urban environmental air quality of the whole province, and the primary pollutant of the urban environmental air quality of the whole province is PM2.5. According to the 2015-2017 "Report on the State of the Environment in Henan Province" published by the Henan Provincial Department of Ecology and Environment, the cities with the top three-year urban air PM2.5 list are Zhengzhou, Anyang, and Jiaozuo. Figure1 is the annual average PM2.5 concentration of various cities in Henan Province in 2017 and 2018.The PM2.5 data in 2017 and 2018 comes from the "Monthly Report on Urban Air Quality" published by the Ministry of Ecology and Environment. On the whole, the PM2.5 concentration of various cities in Henan Province is between 50-75ug/m3, and the area with the highest average concentration is Anyang, Jiyuan, Jiaozuo.

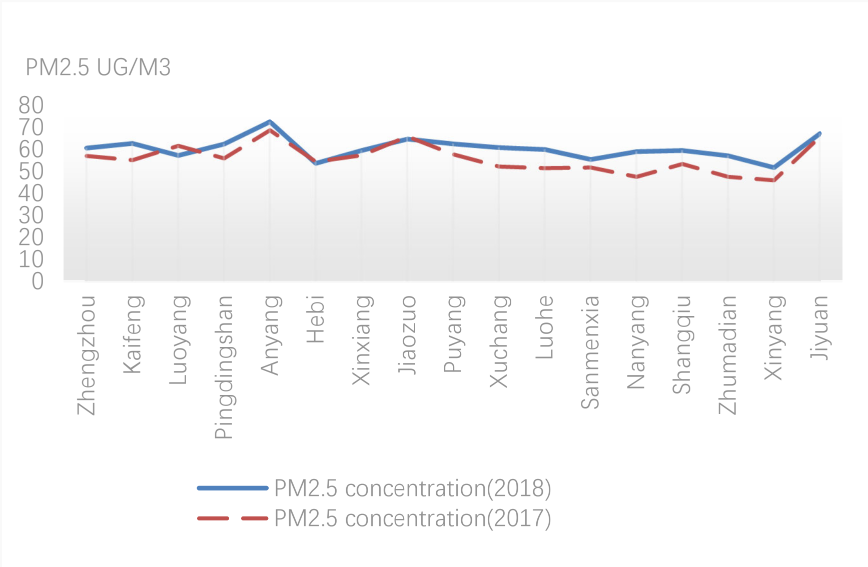

Figure 1. The annual average PM2.5 concentration of each city in Henan Province (2017, 2018)

As shown in Figure1, the PM2.5 concentration distribution shows certain regional differences. High concentration areas are mainly located in the northwestern part of Henan Province, such as Zhengzhou, Anyang, Jiaozuo, Xinxiang, and parts of Luoyang. From the perspective of geographical and meteorological conditions, this part of the region is located at the southern foot of the Taihang Mountains. The dominant winds are northeast and southwest winds throughout the year. The topography, geomorphology and meteorological conditions are not conducive to the dilution and diffusion of atmospheric pollutants [22]. From the perspective of economic and social development, Zhengzhou is the capital city of the province. Its economic aggregate accounts for about 63.7% of the province (according to the 2016 Henan Yearbook). It is also an important transportation hub in the country with a dense population. Jiaozuo, Hebi, and Pingdingshan are cities that grew up due to coal, and their industrial structure is relatively simple. Anyang is an important industrial base dominated by metallurgy, electronics and equipment manufacturing in northern Henan, and its heavy industry has developed rapidly.

Due to the regional differences in the distribution of PM2.5 concentration, this paper selects several major cities in Henan Province to analyze the impact factors of PM2.5 according to geographical locations, including the provincial capital Zhengzhou, Luoyang in the west, Shangqiu in the east, Anyang in the north and the south Xinyang. Due to geographical and historical reasons, these cities also have differences in economy and culture, and each has its own characteristics.

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4. DATA AND METHODOLOGY

4.1. Selection of Indicators

According to the analysis in the literature review and referring to the literature of Debin Lu et al., this article selects 15 factors in five categories to establish an index system: 1. Urbanization and greening, including the level of urbanization, urban population density, and per capita Park green space, green coverage rate in built-up areas; 2. Traffic factors, including the number of civilian cars, highway passenger traffic, and highway freight traffic; 3. Economic development and industrial structure, actual regional GDP, GDP per capita, and secondary industry's total output value The proportion of the tertiary industry in the total output value; 4. Industrial waste gas emissions, including industrial sulfur dioxide emissions, industrial smoke and dust emissions; 5. Energy consumption, including the raw coal consumption of industrial enterprises above designated size and industrial electricity consumption.

Among them, per capita park green space, green coverage in built-up areas, and the proportion of tertiary industry are considered negative indicators, that is, they change in the opposite direction of PM2.5, and the other indicators are positive indicators.

Table 1. Index system of PM2.5 influencing factors

Index layer	Name	Index factors	Unit
Urbanization and greening	X1	Urbanization level	%
	X2	Urban population density	person/km2
	X3	*Park green area per capita	square meters
	X4	*Green coverage rate in built-up area	%
Traffic factor	X5	Number of civilian vehicles	units
	X6	Highway passenger traffic	10,000 people
	X7	Road freight volume	10,000 tons
Economic development and industrial structure	X8	Actual regional output value	100 million yuan
	X9	Real GDP per capita	yuan
	X10	Proportion of secondary industry	%
	X11	*Proportion of tertiary industry	%
Industrial waste gas emissions	X12	Industrial sulfur dioxide emissions	tons
	X13	Industrial smoke and dust emissions	tons
Energy consumption	X14	Industrial power consumption	100 million kWh
	X15	Raw coal consumption of industrial enterprises above designated size	10,000 tons

Source: Henan Statistical Yearbook 2007-2017, China City Statistical Yearbook

Note: 1."*" means negative indicators, the rest are positive indicators;

2.The raw coal consumption of industrial enterprises above designated size is hereinafter abbreviated as "Raw coal consumption"

4.2. Data Source

The PM2.5 data used in the empirical analysis in this paper comes from the Social Economic Data and Application Center of Columbia University, and the global 1998-2016 average PM2.5 raster data obtained with a resolution of 0.01 is processed. The data is Obtained by satellite remote sensing inversion.

Except for the industrial sulfur dioxide emissions from the "China City Statistical Yearbook", the data of various social and economic indicators comes from the "Henan Provincial Statistical Yearbook". This article intends to use data from 2006 to 2016 for analysis. Among them, the raw

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coal consumption data of industrial enterprises above designated size in 2011 is missing, so the data for 2011 is eliminated and only data for 2006-2010 and 2012-2016 are analyzed.

4.3. Research Methods

Since the formation of PM2.5 is a complex process of atmospheric environmental action, pollution sources are diverse, which contain a large amount of unknown information, and the degree of action of each pollution source is different in different regions, which is a gray system. Therefore, this article will use the grey relational analysis method to explore the social and economic influencing factors of PM2.5 in Henan Province.

Grey relational analysis is a branch of grey system theory founded by Professor Deng Julong (1982). Its basic idea is to judge whether the connections between different sequences are close according to the similarity of the geometric shapes of sequence curves. Through grey relational analysis, it is possible to judge which are the main factors from a variety of influencing factors. Its advantages are that it is suitable for small samples, the amount of calculation is small, and the limited assumptions are less restrictive.

The specific method steps are as follows:

First determine the reference sequence X0(t) and comparison sequence Xi(t), t represents time. The expression is as follows:

$$x_0(t) = \{x_0(1), x_0(2), \dots, x_0(m)\},\ t = 1,2,\dots,m$$

$$x_i(t) = \{x_i(1), x_i(2), \dots x_i(m)\},\ t = 1,2,\dots,m;\quad i = 1,2,\dots,n$$

Among them, m is the number of observation times, and n is the number of comparison sequences. The reference sequence in this article is the annual average concentration of PM2.5, and the comparison sequence is the various socio-economic indicators.

Taking into account the problem of non-uniform dimension between different indicators, it is necessary to perform dimensionless processing on each sequence, and transform negative correlation factors into positive correlation factors. The processing method of this paper is to take the negative correlation factors (per capita park green space, green coverage rate of built-up area, and the proportion of tertiary industry) to the inverse, also known as inverted image processing. The dimensionless method is to divide each value in the series by the average value of the series, the formula is as follows:

$$X_iD = (x_i(1)d, x_i(2)d, \dots,\ x_i(t)d), and, x_i(t)d = \frac{x_i(t)}{\overline{X}}, \overline{X} = \frac{1}{m}\sum_{t=1}^{m} x_i(t)$$

Find the correlation coefficient and the degree of correlation, and calculate the correlation coefficient matrix:

$$\xi(x_0(t), x_i(t)) = \frac{\min_i \min_t |x_0(t) - x_i(t)| + \rho \max_i \max_t |x_0(t) - x_i(t)|}{|x_0(t) - x_i(t)| + \rho \max_i \max_t |x_0(t) - x_i(t)|}$$

$\min_i \min_t |x_0(t) - x_i(t)|$ and $\max_i \max_t |x_0(t) - x_i(t)|$ are the minimum value of the range and the maximum value of the range respectively, ρ are the resolution coefficients, which are between 0 and 1, and generally take a value of 0.5.

The correlation degree is the average of the correlation coefficient:

$$\gamma_i = \frac{1}{m}\sum_{t=1}^{m} \xi_i(t)$$

γ_i is the gray correlation degree between the indicators X_i and X_0.

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5. RESULTS AND RECOMMENDATIONS

5.1. Analysis Results

The results of the gray correlation analysis are shown in Table 2. Overall, there are three main factors related to PM2.5 in the five cities in Henan Province selected in this paper: urbanization and greening, industrial structure, energy consumption, and specific details. It is divided into urban population density, urbanization level, per capita green area of parks, green coverage rate in built-up areas, proportion of secondary industry, proportion of tertiary industry, and raw coal consumption of enterprises above designated size. In addition, the PM2.5 concentration of the five cities has relatively low correlation with traffic factors (such as the number of civilian cars) and economic development level (such as the regional GDP).

Table 2. Gray correlation between PM2.5 concentration and various influencing factors

Index layer	Name	Index factors	Zhengzhou	Luoyang	Anyang	Shangqiu	Xinyang
Urbanization and greening	X1	Urbanization level	0.804	0.768	0.811	0.797	0.748
	X2	Urban population density	0.728	0.843	0.778	0.880	0.757
	X3	*Park green area per capita	0.754	0.793	0.815	0.799	0.691
	X4	*Green coverage rate in built-up area	0.846	0.786	0.882	0.819	0.780
Traffic factor	X5	Number of civilian vehicles	0.536	0.564	0.641	0.540	0.616
	X6	Highway passenger traffic	0.579	0.733	0.728	0.690	0.707
	X7	Road freight volume	0.651	0.593	0.641	0.656	0.628
Economic development and industrial structure	X8	Actual regional output value	0.637	0.644	0.677	0.632	0.602
	X9	Real GDP per capita	0.703	0.659	0.669	0.615	0.588
	X10	Proportion of secondary industry	0.859	0.829	0.831	0.872	0.874
	X11	*Proportion of tertiary industry	0.852	0.794	0.789	0.806	0.896
Industrial waste gas emissions	X12	Industrial sulfur dioxide emissions	0.795	0.567	0.834	0.679	0.730
	X13	Industrial smoke and dust emissions	0.675	0.639	0.578	0.677	0.665
Energy consumption	X14	Industrial power consumption	0.671	0.699	0.683	0.738	0.575
	X15	Raw coal consumption of industrial enterprises above designated size	0.745	0.791	0.774	0.775	0.800

In order to more clearly see the correlation between the PM2.5 of each city and the regional economic and social factors, Table 3 lists the top seven factors with the highest correlation to PM2.5 in the five cities. It can be seen that, in addition to the same influencing factors analyzed before, from the perspective of a single city, Anyang's industrial sulfur dioxide emissions are closely related to the PM2.5 concentration in the region. The level of urbanization in Zhengzhou and the raw coal consumption of enterprises in Luoyang and Xinyang are closely related to PM2.5 in the corresponding areas.

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Table 3. Top 7 factors with the highest correlation between 5 cities in Henan and PM2.5

Zhengzhou	Luoyang	Anyang	Shangqiu	Xinyang
Urbanization level 0.804	Population density 0.843	Green coverage rate 0.882	Population density 0.880	Tertiary industry 0.896
Secondary industry 0.859	Secondary industry 0.829	SO2 emissions 0.834	Secondary industry 0.872	Secondary industry 0.874
Tertiary industry 0.852	Tertiary industry 0.794	Secondary industry 0.831	Green coverage rate 0.819	Coal consumption 0.800
Green coverage rate 0.846	Park green area 0.793	Park green area 0.815	Tertiary industry 0.806	Green coverage rate 0.780
SO2 emissions 0.795	Coal consumption 0.791	Urbanization level 0.811	Park green area 0.799	Population density 0.757
Park green area 0.754	Green coverage rate 0.786	Tertiary industry 0.798	Urbanization level 0.797	Urbanization level 0.748
Coal consumption 0.745	Urbanization level 0.768	Population density 0.778	Coal consumption 0.775	Park green area 0.691

In order to more intuitively see the correlation between various social and economic factors in Henan Province and PM2.5, it is illustrated graphically, and the gray correlation analysis results are also supplemented with verification. Let's take Zhengzhou City as an example.

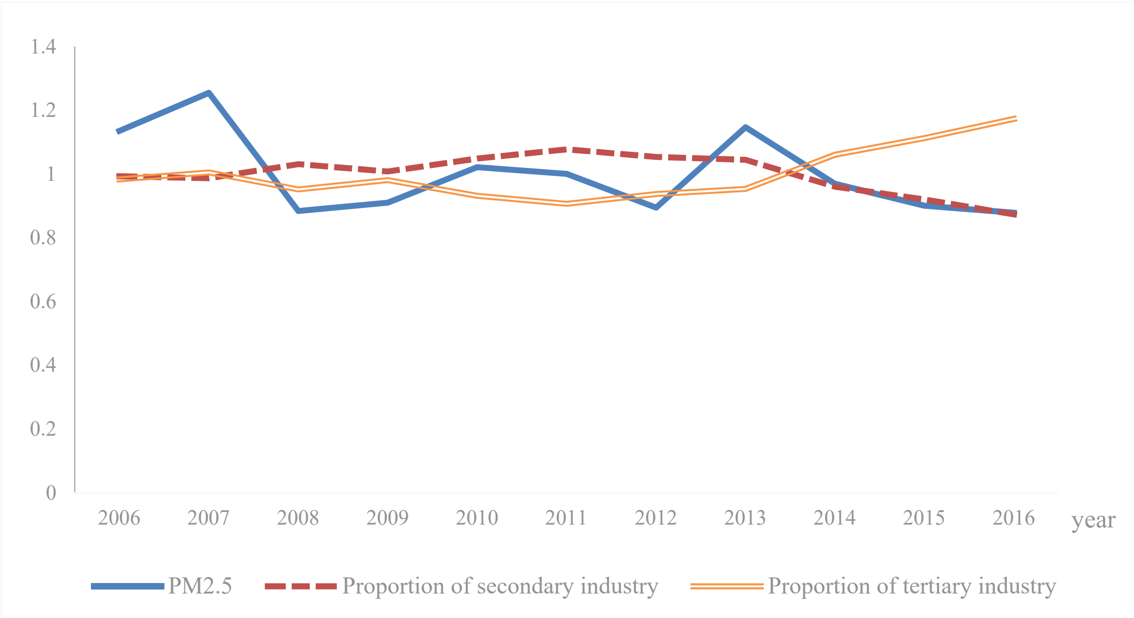

Figure 2. Trends of three indicators in Zhengzhou from 2006 to 2016

Figure 2 shows the change trend of the three indicators of Zhengzhou City from 2006 to 2016, including the annual average concentration of PM2.5, the proportion of the secondary industry in the total output value, and the proportion of the tertiary industry in the total output value. In order to make the three comparable, Respectively, the non-dimensional processing is performed, that is, each value is divided by the mean value of the index sequence. It can be seen from the figure that the similarity of the trends of the three indicators before 2012 is not

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obvious, but after 2013, the PM2.5 concentration of Zhengzhou City began to decline, at the same time, the proportion of the secondary industry began to decline, and the third The proportion of the industry began to rise. It shows that there is a certain correlation between PM2.5 and industrial structure.

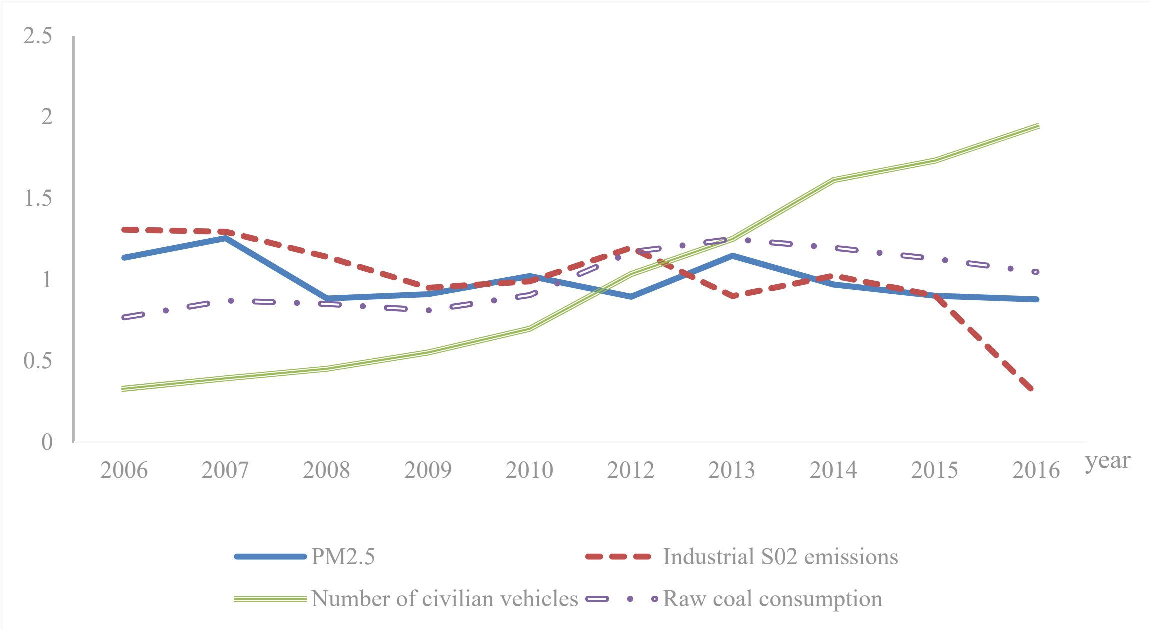

Figure 3. Trends of four indicators in Zhengzhou from 2006 to 2016

Due to the lack of data on the raw coal consumption of industrial enterprises above designated size in each city in 2011, all data in 2011 are removed from the sample here. The processing of missing values in the gray correlation analysis process is also carried out according to this method. It can be seen from the figure 3 that the number of civilian cars has been rising, while the changes in PM2.5 fluctuate, so the increase in the number of cars does not well explain the rise or fall of PM2.5. In connection with the actual situation, we believe that due to the improvement of automobile exhaust treatment technology in recent years and the gradual increase in the proportion of new energy vehicles, the statistical data of the total number of automobiles cannot show a good correlation with the changes in PM2.5. Sex.

5.2. Conclusion and Suggestion

According to the above analysis, there is a great correlation between the industrial structure, urban population density and air pollutant PM2.5 in Henan Province. Since urbanization is an irreversible process, the future urban population will not decrease to a large extent, especially It is a first- and second-tier developed city, but the upgrading of the industrial structure is the general trend. Therefore, the development of high-tech industries, the emphasis on innovation, and the promotion of technological development are things that Henan Province needs to make long-term planning and investment.

In short, Henan Province started late in its development. As a large agricultural province, its industrial development level cannot be compared to other provinces (such as Hebei). However, it has not yet achieved economic rise in itself, but it is facing serious environmental pollution problems. How to choose between economic development and environmental protection, and how to achieve a sustainable, green and efficient development model. This is a huge challenge facing Henan Province, and it cannot be completed in a short time. The government needs to formulate a general direction and promote technology Progress, industrial upgrading, and residents' awareness of environmental protection will be gradually realized.

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