

# Study on the Impact of Urban Sprawl on Air Pollution: A Case Study of Shandong Province

Han Lu

Shandong University of Finance and Economics, Jinan, Shandong 250014, China

hanlu0816@126.com

**Keywords:** urban sprawl; air pollution; ArcGIS.

**Abstract:** This paper takes the panel data of 17 cities in Shandong Province from 2000 to 2016 as a sample, establishes a population and economic model based on the STIRPAT model, and uses the generalized least squares method (FGLS) to measure the impact of urban sprawl on air pollution. The results show that there is widespread urban sprawl in Shandong Province, and urban sprawl reduces air pollution; population size is negatively correlated with air pollution; economic growth, FDI has a significant positive impact on air pollution, and the “pollution paradise” hypothesis is established; public transportation The development is conducive to alleviating air pollution. Therefore, transforming the concept of urban development, establishing an intensive city with optimal population carrying capacity, and promoting the coordinated development of economy, new urbanization and environmental protection are the key measures to mitigate air pollution.

## 1. Introduction

The rapid urbanization has caused the urban sprawl in China to show a disorderly expansion of land growth rate exceeding the population growth rate. The global air quality data released by NASA for 2001-2018 shows that the air quality in Shandong Province is at the end of the world. Therefore, clarifying the relationship and development trend of urban sprawl and air pollution can provide new ideas for controlling air pollution.

The essence of urban sprawl is that the growth rate of urban construction land exceeds the spatial growth mode of its expansion speed in line with the population growth rate and the growth rate of land required for economic development. It is characterized by high speed, low density and “non-compact development”. The disorderly spread of cities will inevitably waste land resources, encroach on green space, increase commuting costs, and consume a lot of energy to build new infrastructure, making air pollution one of the typical negative externalities of the process. The North China region with extremely high PM2.5 concentration in Shandong Province is one of the important reasons for studying this region.

## 2. The empirical measurement of urban sprawl and air pollution

### 2.1 Measurement and analysis of urban sprawl

This paper draws on the SI Spread Index Method, combined with Wang Family and Zhang Junxi, “China's Urban Sprawl Measurement: An Empirical Study Based on Panel Data of 35 Large and Medium-sized Cities” and Hong Shijian and Zhang Jingxiang's Discussion on the Definition of Urban Sprawl and Its Measurements—Taking the Yangtze River Delta As an example, the practice of measuring the urban spread index is as follows:

$$\text{Sprawl\_index} = \text{Smt}/\text{Pmt} \quad (1)$$

Among them, sprawl\_index is the city spread index, Smt is the built-up area of a city at the end of t, and Pmt is the population of the city under the jurisdiction of the city.

This paper uses the average of the urban sprawl index of 17 cities in Shandong Province from 2000 to 2016 to characterize the urban sprawl level of each city. With the help of Stata 14.0, the system

clustering method and the cluster stop judgment rule are used to select the F value to judge the number of categories.

According to the results, the clustering category of the urban sprawl index is set to 3, and the spread clustering of each city is classified as high, high, and low (more intensive), as shown in Table 1.

Table 1 Results of cluster analysis of urban sprawl in Shandong Province from 2000 to 2016

Category	Degree of Urban Sprawl	City
First class	high	Weihai City (2.15), Yantai City (1.65), Dezhou City (1.56) Dongying City (1.55)
Second class	Higher	Binzhou City (1.43), Tai'an City (1.42), Zaozhuang City (1.36), Zibo City (1.31), Laiwu (1.28), Rizhao City (1.308), Jining City (1.21)
Third class	Lower (more intensive)	Weifang City (1.14), Liaocheng City (1.11), Heze City (1.07), Linyi City (1.06), Qingdao City (1.04), Jinan City (1.00)

## 2.2 Measurement and analysis of air pollution

In combination with the WHO and the "Environmental Air Quality Standards" issued by China in 2012, the pollution in Shandong Province has been seriously exceeded in recent years. The PM2.5 concentration is divided into six levels based on actual conditions. As shown in Table 2:

Table 2 PM2.5 concentration interval scale table (unit:  $\mu\text{g}/\text{m}^3$ )

PM2.5 Concentration Interval	Grade
25 or less	Excellent +
25-35	excellent
36-45	good
46-55	Mild pollution
56-65	Moderately polluted
66-75	Heavier pollution
75 and above	Severe pollution

Connect the PM2.5 value to ArcGIS and customize the classification according to the above criteria to derive the PM2.5 mean value of the 17th prefecture-level city in Shandong Province from 2000 to 2016. The results show that: Shandong Province 2000-2016, all prefecture-level cities The average value of PM2.5 is higher than 35, which exceeds the compliance concentration set by WHO and China, and decreases from coastal to inland. The main reasons are as follows: First, the total amount of atmospheric pollutants discharged. Most of the cities with moderate pollution and heavy pollution are more developed in the secondary industry and have a greater impact on the quality of the atmosphere. The second is the topographical factor. The cities with the highest degree of pollution are topographically flat, surrounded by mountains or backed by mountains. The flow of atmospheric pollutants spreads slowly and gathers in the upper or adjacent areas. The third is the spread of pollutants. Jinan is the center, surrounded by mountains on three sides, and the pollutants spread slowly, but it affects the surrounding areas. Therefore, the pollution in Binzhou and other cities is more serious. Weihai and Yantai are open to the public, and the third is facing the sea. The pollutants are easy to spread, so the air quality is good.

## 3. Empirical analysis of urban pollution on air pollution

### 3.1 Inspection of the relationship between urban sprawl and air pollution

By comparing the relationship between urban sprawl and PM2.5 concentration in Shandong

Province from 2000 to 2016, it is found that the trend of urban sprawl in Shandong Province and the trend of PM2.5 concentration are in good agreement, especially in the case of “Binzhou – Zaozhuang”. To the east, the reverse trend of the two is almost the same, that is, the higher the urban spread, the smaller the PM2.5 value, so it can be assumed that:

Urban sprawl in Shandong Province is negatively correlated with air pollution.

### 3.2 Model setting

Dietz and Rosa obtained a stochastic model of environmental impact STIRPAT based on IPAT identity studies. The basic form is:

$$I_{mt} = aP_{1mt}^b A_{2mt}^c T_{3mt}^d e_{mt} \quad (2)$$

Among them,  $I_{mt}$ ,  $P_{1mt}^b$ ,  $A_{2mt}^c$ , and  $T_{3mt}^d$  respectively indicate the population, wealth, and technology of the country at time  $t$ .  $a$ ,  $b$ ,  $c$ , and  $d$  represent variable parameters, and  $e_{mt}$  represents random errors.

Based on this model, this paper analyzes the impact of urban sprawl on PM2.5. Combined with the nature of urban sprawl and its main influencing factors, this paper introduces the following related variables:  $P$  is expressed by urban sprawl and city scale, and  $A$  uses GDP per capita and GDP increase. The proportion, the actual FDI indicates that  $T$  is expressed by the level of urban infrastructure construction. To highlight the impact of urban sprawl on atmospheric pollution, adjust the model as follows:

$$\ln PM2.5_{m,t} = a + b * \ln sprawl\_index_{m,t} + c * \ln citysize_{m,t} + \sum a X_{m,t} + e_{m,t} \quad (3)$$

$m$  represents the prefecture-level city,  $t$  represents 2000-2016,  $PM2.5$  represents the annual average PM2.5 concentration of each city,  $sprawl\_index$  represents the urban sprawl index,  $citysize$  represents the city size, expressed by the city's total population at the end of the year and urban GDP. ,  $a$ ,  $b$ ,  $c$ ,  $d$  represent variable coefficients, and  $e_{m,t}$  represents random error.

### 3.3 Variable selection

Air pollution index (PM2.5) in  $\mu g/m^3$ .

City Spread Index ( $sprawl\_index$ ).

The city scale uses the population at the end of the year to indicate the population size, and the unit is 10,000; the GDP of each city indicates the scale of economic development, and the unit is 100 million yuan.

The level of urban development is expressed in terms of per capita GDP ( $P\_GDP$ ) (in yuan), the proportion of added value of GDP in GDP ( $s\_ist$ ), and the amount of FDI in real use (in units of 100 million yuan).

Select the actual paved road area (units of 10,000 square meters) at the end of the year, the per capita paved road area ( $p\_road$ ) (in square meters) and the number of public steam (electric) vehicles ( $p\_bus$ ) and the green area of the built-up area. The rate represents the level of urban infrastructure construction. Because the paved road area is larger, residents are more likely to choose private cars to travel, which is more likely to increase environmental pollution. Compared with traffic congestion, smooth travel can reduce vehicle exhaust emissions. From the source, the higher the development of public transport system, the more it can reduce vehicle exhaust emissions. From the perspective of governance, the higher the green coverage rate in the built-up area, the more it can reduce the damage of environmental pollution.

### 3.4 Analysis of empirical results

The empirical analysis data of this paper is the variable panel database of 17 prefecture-level cities in Shandong Province from 2000 to 2017, which contains all variable values.

Model 1 Population Model:

$$\ln PM2.5_{mt} = a + b \ln sprawl\_index_{mt} + c \ln population_{mt} + d s\_ist_{mt} + f \ln P\_GDP_{mt} + g \ln FDI_{mt} + h \ln road_{mt} + i \ln p\_road_{mt} + j \ln p\_bus_{mt} + k \ln green_{mt} + e_{mt} \quad (4)$$

## Model II Economic Model:

$$\ln PM2.5_{mt} = a + b \ln sprawl\_index_{mt} + c \ln GDP_{mt} + d s\_ist_{mt} + f \ln P\_GDP_{mt} + g \ln FDI_{mt} + h \ln p\_road_{mt} + i \ln p\_road_{mt} + j \ln p\_bus_{mt} + k \ln green_{mt} + e_{mt} \quad (5)$$

The empirical analysis of this paper uses panel data, first using the Hausman test to select a fixed effect (FE) model or a random effects (RE) model.

Due to the problems of panel data, Wooldridge test is used to judge whether there is autocorrelation in the group; Greene is used to check whether there is heteroscedasticity between groups; Pesaran test method, Friedman, Frees test method verification group Contemporaneity. The results show that both models select the fixed effect (FE) model, and there is a strong intra-group autocorrelation and inter-group synchrony, so the generalized least squares (FGLS) method is used to estimate the impact of urban sprawl on air pollution. The results and the estimated results are summarized and found:

(1) Under the two models, the impact of sprawl\_index on PM2.5 concentration was significantly negative at 1%, urban sprawl index increased by 10%, and PM2.5 concentration decreased by 0.2%-0.4%.

(2) In the population model, the impact of the city size represented by the population at the end of the year on the PM2.5 concentration is -0.33, that is, for every 10% increase in urban population at the end of the year, PM2.5 concentration pollution decreases by 3.3%. From the classification of PM2.5 concentration, cities with heavy pollution are more volatile than those with light pollution. The data show that the per capita built-up area of China is high, and the population growth will inevitably lead to the rapid expansion of the built-up area and the reduction of pollution within the unit area, and the residents' demands for environmental quality will increase with the advancement of new urbanization.

(3) In the economic model, the economic scale elasticity of PM2.5 concentration is 0.26, indicating that for every 10% increase in urban economy, PM2.5 concentration increases by 2.6%. Urban economic development leads to building construction, industrial agglomeration and rigid demand for energy. Under the same technical level, PM2.5 concentration is getting higher and higher; urban scale increases lead to commuting distance and time, urban logistics transportation distance increases, traffic The increase in energy consumption in the transportation sector has led to an increase in PM2.5 concentrations.

(4) The regression results show that the impact of the industrial output on the PM2.5 concentration is weaker by the proportion of the added value of the secondary production to the GDP. This is because the industrial structure of most cities changed slightly during 2000-2016, but it is still affirmative. The positive effect of industry on air pollution.

(5) The regression results show that the impact coefficient of the external opening level represented by the foreign-invested actual investment (FDI) on the PM2.5 concentration is 0.06, which indirectly confirms that the "pollution paradise" hypothesis was established in Shandong Province. Due to the geographical environment and abundant labor resources, Shandong Province has opened up a number of cities earlier and has attracted a lot of investment. Some of these cities have introduced polluting enterprises to stimulate the economy.

(6) As far as urban infrastructure is concerned, for every 10% increase in per capita paved road area, PM2.5 concentration will increase by 0.6%-0.7%. The increase in road paving area has increased the reach of travel and promoted the development of real estate along the line, resulting in the city not reaching a better carrying capacity and spreading, thereby increasing air pollution. And for every 10% increase in the number of public steam (electric) vehicles, the PM2.5 concentration is reduced by 0.3%. The more public transportation there is, the more developed the public transportation system is. The more people prefer the public transportation system when traveling, the direct reduction of the use of private cars, thus reducing the emissions of automobile exhaust, the key is to reduce the fuel consumption caused by traffic congestion.

## **4. Conclusions and policy recommendations**

### **4.1 Conclusion**

#### **4.1.1. Urban sprawl in Shandong Province**

(1) There is a phenomenon of urban sprawl in the whole Shandong Province from 2000 to 2016. The overall situation is that the southwest is low and the northeast is high. It is bounded by the central city of Binzhou-Zaozhuang and gradually rises to the east and west sides; 2) The degree of urban sprawl in central and western Shandong Province is closely related to the level of economic development. Per capita GDP is negatively correlated with urban sprawl. (3) The dominant factors of urban sprawl in cities in Shandong Province are not completely unified, such as economic development level and urban planning layout, environmental quality, government policies, etc.

#### **4.1.2. Status of air pollution in Shandong Province**

(1) The average value of PM<sub>2.5</sub> concentration in Shandong Province from 2000 to 2016 is higher than 35, exceeding the target concentration set by WHO and China, and showing a trend of decreasing coastal inland; (2) PM<sub>2</sub> in 17 cities of Shandong Province .5 both showed a volatility upward trend, and the peak occurrence years were highly consistent, roughly in 2003, 2008, 2011 and 2014, and after the 2008 peak, the growth rate decreased and stabilized. This is related to government policies and the law of air pollution.

#### **4.1.3. The impact of urban sprawl on atmospheric pollution**

(1) The urban sprawl index is negatively correlated with air pollution. The area of urban construction land expands with the expansion of the urban population. Secondly, the spread of land use in China is higher than the population growth rate, which makes the concentration of atmospheric pollutants per unit area lower, which supports the above conclusions. At this stage, economic growth will add significant gas pollution. Shandong's economic growth mainly depends on industry, and the technical level is imperfect and the energy utilization efficiency is low. It is easy to add significant gas pollution; (2) The "pollution paradise" hypothesis is based on this research in Shandong Province. The share of foreign capital is an important force driving the economy of Shandong Province. In the past years, the government's assessment system has brought foreign investment enterprises a high GDP return while exacerbating atmospheric pollution. (3) Based on the development of public transport and road networks, urban sprawl is conducive to Improve air pollution. The development of public transport has reduced the use of private cars, and the accessibility of roads is high, making it easy to achieve compact urban space.

### **4.2 Policy recommendations**

1) Reasonably formulate urban planning and improve urban space utilization. When formulating urban planning, we must resolve the contradiction between urban planning and land use planning, improve urban space utilization, pay attention to "human urbanization" and "industrial urbanization", and focus on economic and social development, focusing on unit area output efficiency. Effectively protect land, especially cultivated land resources.

2) Construct an intensive city with optimal population carrying capacity. The dense population in the city center often causes the illusion of high population density. It requires the government not only to do a good job of transferring people to settle down, but also to improve the city's industrial competitiveness and population attractiveness, and to enhance the city's sustainable development capabilities.

3) Strict foreign investment access standards and promote the "green growth" industry development model. It is necessary to formulate strict foreign investment access rules and implement them, especially environmental standards, and on the basis of economic development, rationally plan the industrial development layout, promote the optimization and upgrading of industrial structure, do a good job of converting old and new kinetic energy, and introduce or develop environmentally friendly production technologies. Process, develop and use clean energy to mitigate atmospheric

pollution from the source.

4) Construct an intensive compact city with “high density, functional mix and bus guidance”. Combined with the actual situation of Shandong Province, in the future urban planning, we can selectively learn from foreign "new urbanism" and other theories to achieve optimal population distribution and optimal urban layout.

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