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## Research on prediction of municipal solid waste production based on Grey Relation Analysis and Grey Prediction Model

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# Research on prediction of municipal solid waste production based on Grey Relation Analysis and Grey Prediction Model

Zhiguo Fan, Yanjun Fan\*

School of Management, Tianjin University of Technology, Tianjin, China

\*Corresponding author e-mail: 1208839223@qq.com

**Abstract.** The amount of municipal solid waste (MSW) is the basic data of municipal solid waste management. It is an important basis for urban green planning to predict MSW output scientifically and accurately. Therefore, first this paper uses Grey Relation Analysis, and points out that the main factor affecting the production of municipal solid waste is the urban resident population. Then the Grey Prediction Model is used to predict the amount of MSW in Shanghai from 2005 to 2020. The prediction results show that the amount of MSW in Shanghai will reach 8.86 million tons in 2020. Finally, in view of the above analysis, this paper puts forward some countermeasures, so as to provide reference for the future environmental planning in Shanghai.

## 1. Introduction

With the rapid development of China's economy and the acceleration of urbanization, municipal solid waste is growing rapidly. A large amount of MSW has become a social problem that puzzles the city planning, pollutes the urban environment, and affects the life of citizens. According to the data in Shanghai Statistical Yearbook, the MSW in Shanghai increased from 6.22 million tons in 2005 to 8.8 million tons in 2016, showing an explosive growth trend [1]. Therefore, the analysis and prediction of the production of municipal solid waste can provide scientific decision-making information for urban environmental planning and total amount control, so as to realize the "reduction, resource and harmlessness" of urban domestic waste.

At present, most scholars mainly focus on two aspects of municipal solid waste. On the one hand, factors affecting the generation of municipal solid waste are analyzed, and different factors have different effects on municipal solid waste. For example, Zhao Yan selected five influential factors, such as urban population, GDP, urban built-up area, per capita disposable income and per capita consumption expenditure, as the factors to analyze the amount of municipal solid waste in 31 provinces of China [2]; Zheng Wen selected 11 factors such as GDP, resident population at the end of the year, investment in environmental protection, area of road cleaning and so on, to carry on the relation analysis to the amount of municipal solid waste in Shenzhen [3]. On the other hand, scholars use appropriate prediction methods to predict the amount of garbage production in order to provide reference suggestions for the future planning of cities. The method for predicting the production volume of municipal solid waste include the grey system model, the system dynamics, the combination forecast and the neural network prediction [4]. For example, Ma Huimin uses BP neural network prediction model to analyze and predict municipal solid waste production in Shanghai [5]. Using Grey forecasting Model, Zhang Houhu forecasts the amount of municipal solid waste removal in Jiangsu Province [6].

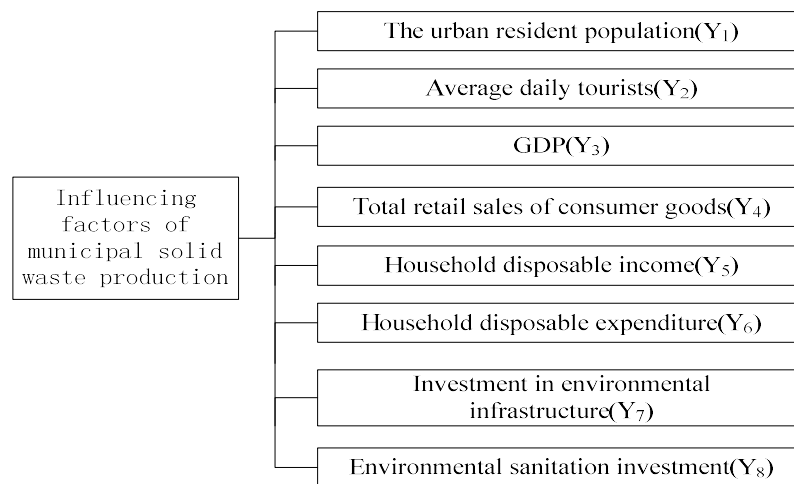


By combing the relevant literature, it is found that the scholars have made a great deal of research on the urban municipal solid waste. Therefore, on the basis of the existing research, this paper firstly analyzes the factors that affect the production of municipal solid waste in Shanghai, and then uses the grey forecasting model to predict the short-term output of the municipal solid waste in Shanghai, finally provides reference value for future planning of Shanghai.

## 2. Grey Relational Analysis of influencing factors of municipal solid waste production

### 2.1. Index selection

As shown above, the amount of municipal solid waste produced is the result of a combination of many influencing factors. Based on the existing research, this paper selects 8 indicators, such as the urban resident population, average daily tourists, GDP, total retail sales of consumer goods, household disposable income, household disposable expenditure, investment in environmental infrastructure and environmental sanitation investment. As shown in figure 1, these indicators have different effects on municipal solid waste in different degrees.



**Fig. 1** Influencing factors of municipal solid waste production

### 2.2. Grey relational analysis

Grey relational analysis is a gray analysis method proposed by Professor Deng Julong. Its essence is to judge the degree of correlation between the factors by comparing the set of data which can reflect the characteristics of the change of the factors [7]. The specific analysis steps are as follows:

(1) Standardized initial data. In order to reduce the influence of random factors, the initial data need to be standardized because of the different measurement units of each factor. The standardized calculation formula is as follows:

$$y_i^* = \frac{y_i(n)}{y_i(1)}, (i = 1, 2, \dots, t; n = 1, 2, \dots, m) \quad (1)$$

The calculated data sequence forms the following matrix:

$$(Y_0, Y_1, \dots, Y_t) = \begin{pmatrix} y_0(1) & y_1(1) & \cdots & y_t(1) \\ y_0(2) & y_1(2) & \cdots & y_t(2) \\ \vdots & \vdots & \cdots & \vdots \\ y_0(m) & y_1(m) & \cdots & y_t(m) \end{pmatrix}$$

This paper inquiries the statistical yearbook of Shanghai from 2005 to 2016, collects the original data of the related indexes, and standardizes the original data. The result of calculation is shown in Table 1.

**Table 1.** Standardization of influencing factors of municipal solid waste in Shanghai from 2005 to 2016

Year	Y <sub>1</sub> (Ten thousand people)	Y <sub>2</sub> (Per person / day)	Y <sub>3</sub> (Trillions)	Y <sub>4</sub> (100 million yuan)	Y <sub>5</sub> (yuan)	Y <sub>6</sub> (yuan)	Y <sub>7</sub> (100 million yuan)	Y <sub>8</sub> (100 million yuan)
2005	1	1	1	1	1	1	1	1
2006	1.039	1.060	1.143	1.133	1.109	1.071	0.885	0.662
2007	1.092	1.165	1.351	1.300	1.267	1.253	1.160	0.773
2008	1.133	1.121	1.522	1.536	1.431	1.408	1.415	1.305
2009	1.169	1.101	1.627	1.749	1.547	1.524	1.407	1.426
2010	1.218	1.494	1.856	2.076	1.708	1.685	1.466	0.703
2011	1.242	1.431	2.076	2.412	1.943	1.823	1.576	1.557
2012	1.259	1.401	2.182	2.631	2.155	1.906	1.424	1.546
2013	1.278	1.326	2.359	2.872	2.352	2.044	1.414	0.815
2014	1.283	1.385	2.549	3.123	2.559	2.216	1.352	0.613
2015	1.278	1.401	2.716	3.400	2.675	2.526	1.227	1.204
2016	1.280	1.491	3.009	3.674	2.913	2.719	1.587	1.066

(2) Calculated two-level difference, two-level minimum difference, and two-level maximum difference:

$$\Phi(n) = |y_0(n) - y_i(n)| \quad (2)$$

$$\Phi_{\min} = \min_{i=1}^t \min_{n=1}^m |y_0(n) - y_i(n)| \quad (3)$$

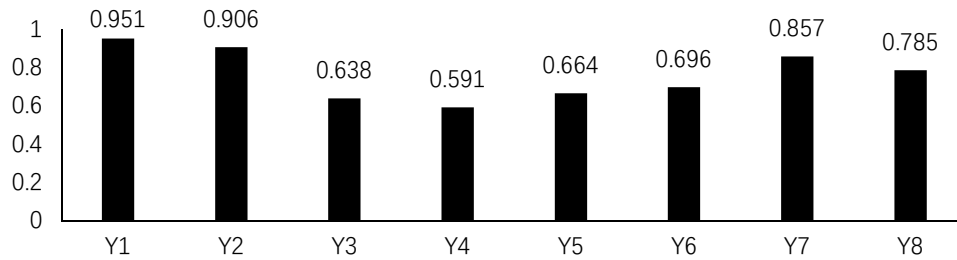
$$\Phi_{\max} = \max_{i=1}^t \max_{n=1}^m |y_0(n) - y_i(n)| \quad (4)$$

(3) Calculated relation degree:

$$\delta_i(n) = \frac{\Phi_{\min} + \eta \Phi_{\max}}{\Phi(n) + \eta \Phi_{\max}} \quad (n = 1, 2, \dots, m; \eta = 0.5) \quad (5)$$

$$\tau_{0n} = \frac{1}{m} \sum_{n=1}^m \delta_i(n) \quad (6)$$

The correlation degree between the amount of municipal solid waste production and the influencing factors is calculated by above step. The result is shown in figure 2.



**Fig. 2.** Relation between influential factors and production of municipal solid waste in Shanghai from 2005 to 2016

As can be seen from figure 2, the order of correlation among the factors that affect the production of municipal solid waste in Shanghai is as follows: This indicates that the main factors affecting the production of urban municipal solid waste are the number of urban resident population, followed by the number of average daily tourists, the amount of investment in environmental sanitation, the household disposable income and expenditure, and finally the GDP of this city, and so on. It shows that the increase of population makes the production of urban municipal solid waste increase, and to a certain extent, it restricts the sustainable development of the city.

### 3. Urban municipal solid waste production based on Grey Prediction Model

#### 3.1. Grey Prediction Model

Grey prediction is a method of forecasting grey systems. Grey prediction is to find the law of system change by generating and processing the original data, to generate the data series with strong regularity, and then to establish the corresponding differential equation model, so as to predict the development trend in the future [8]. The calculation steps are as follows:

(1) Established the original data sequence and accumulated it:

$$Y^{(0)} = \{y^{(0)}(1), y^{(0)}(2), \dots, y^{(0)}(m)\} \quad (7)$$

$$Y^{(1)}(n) = \sum_{j=1}^n y^{(0)}(j), (j=1, 2, \dots, m) \quad (8)$$

(2) Established GM model (First order ordinary differential equation:

$$\frac{dY^{(1)}}{dt} + fY^{(1)} = g \quad (9)$$

$f, g$  are constants, which can be obtained by least square fitting:

$$\hat{f} = [f, g]^T = (G^T G)^{-1} G^T B \quad (10)$$

$$\text{Which: } B = \begin{bmatrix} y^{(0)}(2) \\ y^{(0)}(3) \\ \dots \\ y^{(0)}(m) \end{bmatrix}, G = \begin{bmatrix} -\frac{1}{2}(Y^{(1)}(1) + Y^{(1)}(2)) & 1 \\ -\frac{1}{2}(Y^{(1)}(2) + Y^{(1)}(3)) & 1 \\ \dots & \vdots \\ -\frac{1}{2}(Y^{(1)}(m-1) + Y^{(1)}(m)) & 1 \end{bmatrix}$$

The solution of this differential equation is:

$$\hat{Y}^{(1)}(n+1) = \left( Y^{(0)}(1) - \frac{g}{f} \right) e^{-fn} + \frac{g}{f}, (n=1,2,\dots,m) \quad (11)$$

(3) Predictive value for the original sequence:

$$\hat{Y}^{(0)}(n+1) = \hat{Y}^{(1)}(n+1) - \hat{Y}^{(1)}(n), (n=1,2,\dots,m) \quad (12)$$

(4) Checked model:

In this paper, the method of precision check is adopted, and the relative error is as follows:

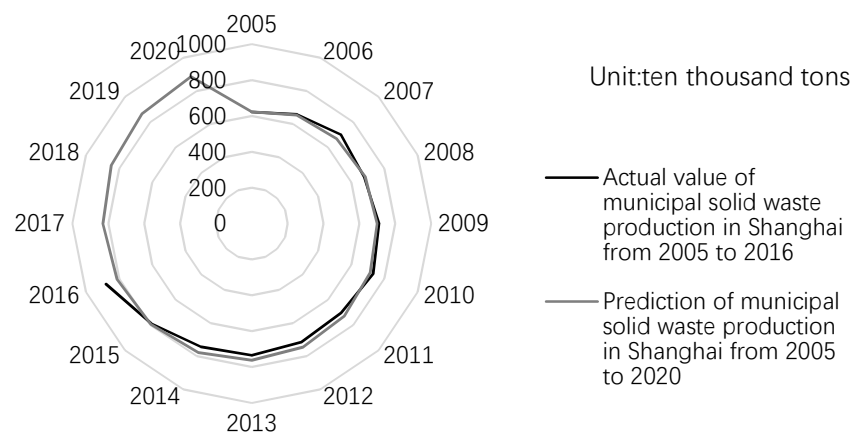
$$\nu(n) = \frac{Y^{(0)}(n) - \hat{Y}^{(0)}(n)}{Y^{(0)}(n)} \times 100\%, \text{ the average relative error is } \nu(\text{avg}) = \frac{1}{m-1} \sum_{n=2}^m |\nu(n)|, \text{ the precision}$$

is  $P = [1 - \nu(\text{avg})] \times 100\%$ , When  $P$  is closer to 1, it shows that the prediction effect of the model is better, and vice versa.

### 3.2. Model application

In this paper, the amount of municipal solid waste production in Shanghai from 2005 to 2016 was used as the original data: (622,658,702,678,710,732,704,716,735,743,790,880). According to the step of the grey prediction model above, the prediction value of the original data can be obtained as follows:

$\hat{Y}^{(1)}(k+1) = 30169e^{0.0215k} - 29547$ , the precision of model check is:  $P = 97\%$ , since the precision of model check is close to 100%, it is shown that the grey prediction model has a good prediction effect. Because the grey forecasting model has high precision for short-term prediction, this paper forecasts the amount of municipal solid waste production in Shanghai by 2020, as shown in figure 3.



**Fig. 3.** Comparison of actual and predicted values of municipal solid waste production in Shanghai from 2005 to 2020

As can be seen from figure 3, the actual value of municipal solid waste production is almost in agreement with the predicted value, indicating that the short-term prediction results of the grey prediction model are more accurate and can predict the amount of urban waste production in the recent period of time. Furthermore, it provides practical guidance for urban garbage treatment and planning.

#### 4. Conclusion

On the basis of analyzing the influencing factors of municipal solid waste production, a prediction model of municipal solid waste production in Shanghai based on grey relational analysis and grey prediction is established in this paper, and the following conclusions are obtained.

(1) As a quantitative analysis method, grey relation analysis can not only measure the correlation between municipal solid waste production and its influencing factors, but also determine the main factors that affect the amount of municipal solid waste production.

(2) The main influencing factors of urban municipal solid waste production are the urban resident population, average daily tourists, GDP, total retail sales of consumer goods, household disposable income, household disposable expenditure, investment in environmental infrastructure and environmental sanitation investment etc. At the same time, the urban resident population is the main factor among the many factors that affect the amount of municipal solid waste.

(3) By establishing the grey prediction model of municipal solid waste production and comparing the prediction result with the actual result, it is found that the results are almost identical, which shows that the prediction effect of this model is better.

In order to reduce the amount of municipal solid waste and realize sustainable development, this paper puts forward some countermeasures and suggestions for Shanghai. First of all, we should enhance the awareness of environmental protection by strengthening the publicity of environmental protection, starting from the source of waste management, energy saving and pollution reduction, less waste, prohibition of littering, recycling of resources, and so on, so as to better reduce the amount of waste production. Secondly, by the coordination of the relevant departments, we should establish the laws and regulations on environmental protection, and ensure the effective implementation, through the means of compulsory supervision to improve the intensity of the environmental protection of the city. Finally, reasonable classification and treatment of garbage can also reduce the pollution of the environment. Therefore, a reasonable garbage classification and recycling mechanism should be established to deal with garbage scientifically, so as to achieve the goal of environmental protection and greenness of the city.

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