Present situation of hazardous waste generation in China and grey model prediction

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Abstract. According to the 2008-2017 China Environmental Statistics Yearbook data, combined with GIS heat map, the current situation and regional distribution characteristics of hazardous waste generation and disposal in China were analyzed, and the GM gray model was constructed to predict its output in the next five years. The results show that it is predicted that by the end of 2023, hazardous waste production of China will reach 157,889,300 tons. It is suggested that take the government as the guidance, the production and disposal enterprises will jointly promote the development of hazardous waste resources, improve the existing treatment methods and strengthen the hazardous waste management system, thus breaking the deadlock of geographical mismatch.

1. Introduction

In recent years, China has caused great concern at home and abroad due to the existence of hazardous waste. Therefore, how to control hazardous waste pollution is a key issue that the Chinese government needs to solve urgently.

So far, academic research on hazardous waste in China has focused on the construction of disposal facilities, source supervision, and responsibility for hazardous waste disposal. Sun Ning et al [1] conducted a comprehensive review of the National Hazardous Waste and Medical Waste Disposal Facilities Construction Plan. The analysis pointed out that there are five problems in the construction and operation of the project, such as layout, process technology, difficulty in collecting waste, lack of ability of operating enterprises and poor support for R&D industrialization. Yang Changqing et al [2] believe that the supervision of the source of hazardous waste needs to start from the EIA. For the enterprises that cause hazardous wastes to pay attention to the training of relevant laws and regulations, enterprises that use hazardous waste should focus on strengthening daily monitoring and account management; Jiang Yunfei et al [3] suggested that on the basis of the principle of government leadership, pluralistic governance, and the principle of power and responsibility, Adopt a classification, sub-item, stratification, and step-by-step approach to construct a framework of government responsibility in the management of hazardous wastes from social sources. In addition, Chen Narong [4] and others believe that the GM (1,1) model is more intuitive and accurate than the GM (1,3) model, and can better predict the trend of industrial solid waste production in the next few years.

On this basis, this paper innovatively uses GIS to establish a heat map of hazardous waste distribution, which provides a visual reference for analyzing the distribution status of hazardous waste generation and disposal in China. Using grey theory and GM model to predict the production of
hazardous waste, it provides a reliable basis for the management and disposal of hazardous waste in China.

2. Situation of production of hazardous waste
This paper uses the 10-year hazardous waste output published in the 2008-2017 China Environmental Statistics Yearbook[5] as the raw data, as shown in Table 1. Since 2011, China's hazardous waste production has increased by spurt. From 2011 to 2015, the annual production of hazardous waste was more than 30 million tons. In 2017, the national hazardous waste output was 6936.89, accounting for 2.09% of the total industrial solid waste production in that year. The utilization, hazardous waste disposal and hazardous waste storage accounted for 58.29%, 12.55% and 36.78% of the hazardous waste production in the current. (The ratio of each flow to production is shown in Figure 1.)

| Years | Industrial solid waste production ($10^4$ t) | Hazardous production ($10^4$ t) | Hazardous waste ratio (%) | Comprehensive utilization ($10^4$ t) | Disposal ($10^4$ t) | Storage ($10^4$ t) |
|-------|--------------------------------------------|---------------------------------|---------------------------|-------------------------------------|-------------------|------------------|
| 2011  | 322772                                     | 3431.22                         | 1.06%                     | 1773.05                             | 916.48            | 823.73           |
| 2012  | 329044                                     | 3465.24                         | 1.05%                     | 2004.64                             | 698.21            | 846.91           |
| 2013  | 327702                                     | 3156.89                         | 0.96%                     | 1700.09                             | 701.2             | 810.88           |
| 2014  | 325620                                     | 3633.52                         | 1.12%                     | 2061.8                              | 929.02            | 690.62           |
| 2015  | 327079                                     | 3976.11                         | 1.22%                     | 2049.72                             | 1173.98           | 810.3            |
| 2016  | 309210.34                                  | 5347.30                         | 1.73%                     | 2823.71                             | 1605.80           | 1158.26          |
| 2017  | 331592.10                                  | 6936.89                         | 2.09%                     | 4043.42                             | 2551.56           | 870.87           |

![Figure 1. Proportion of China's hazardous waste flows.](image)

From Figure 1, we can get the overall trend of hazardous waste in China: Since 2012, the disposal rate of hazardous waste has increased significantly, and the comprehensive utilization rate has been fluctuating. The dangerous waste disposal rate and the effective improvement of the comprehensive utilization rate of hazardous waste will inevitably lead to a decline in the hazardous waste storage rate. [6] In 2017, the number of national hazardous waste licenses (including medical hazardous wastes) was 2,722, of which Jiangsu and Zhe jiang received the largest number of hazardous waste treatment business licenses, 336 and 240 respectively. It can be seen that the Chinese government pays more and more attention to the management of hazardous wastes. The comprehensive utilization and disposal capacity of hazardous wastes in all regions has been significantly improved compared with earlier years. The discharges of hazardous wastes have been declining year by year, and zero emissions have been basically achieved.

3. Regional distribution characteristics of hazardous waste
This paper divides the Chinese region into the east, middle and west according to the first level; according to the second level, China is divided into North China, East China, South China, Central China, Southwest China and Northwest China. On this basis, through the waste production and the end of the two ports, use GIS to make a thermal map for visual analysis.
3.1. The interface of waste generation and disposal

It can be seen from Figure 2 that between 2008 and 2017, the largest hazardous waste production in China is in the eastern region (including East China, North China, South China, and Northeast China), accounting for 58.88% of the total hazardous waste in the country, including hazardous waste production in East China. Ranked first, accounting for 38.31% of the total national hazardous waste. The areas with high hazardous waste production in the eastern region are mainly concentrated in industrially developed coastal cities, which are consistent with the industrial distribution characteristics of industrial hazardous waste. Followed by the western region (including southwest and northwest), accounting for 31.01% of the total national hazardous waste production, of which the northwest region ranked second in hazardous waste production, accounting for 19.84% of the country's total hazardous waste.

![Figure 2. Total national hazardous waste production.](image1)

From Figure 3, the most hazardous waste disposal in the decade is the eastern region, accounting for 71.06% of the total hazardous waste disposal in the country, of which the East China region has the strongest disposal capacity, accounting for 38.72% of the total national hazardous waste disposal.

![Figure 3. National hazardous waste disposal volume.](image2)

Followed by the North China region, the disposal volume accounted for 12.80%. China's hazardous waste production shows obvious regional characteristics: industrialized areas located in eastern and northwestern China account for more than 50% of hazardous waste production, but most of the disposal capacity of hazardous waste industries are concentrated in economically developed areas such as East China and North China. The government’s restrictions on the transfer of hazardous wastes across provinces have further exacerbated geographical mismatches.

4. Grey prediction model

4.1. GM (1, 1) prediction model

The GM(1,1) model is a way to predict gray systems that contain both known parameters, unknowns, and uncertain parameters. It only requires short-term observations, with less raw data required and high accuracy. [7]

4.2. Modeling steps

The differential equation of GM(1,1) is: \( \frac{dx}{dt} + ax = u \), if \( x^0 = [x^0(1), x^0(2), \ldots, x^0(n)] \) was a column of raw data, that is, the parent sequence, it is cumulatively generated:
\[ (1 - \text{AGO}) x^{(i)}(k) = \sum_{m=1}^{k} x^{(m)}(t) \]  

\[ x^{(i)} = [x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)] = [x^{(0)}(1) + x^{(0)}(2) + x^{(0)}(3) + \ldots + x^{(0)}(t-1) + x^{(0)}(t)] \]

The differential equation of the following whitening form can be established:
\[ \frac{dx}{dt} + ax = u , \]

The parameters a, u are solved by the least squares method:
\[ \begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T Y_n \]  

\[ \begin{bmatrix} -\frac{1}{2} \left[ x^{(i)}(1) + x^{(i)}(2) \right] & 1 \\ -\frac{1}{2} \left[ x^{(i)}(2) + x^{(i)}(3) \right] & 1 \\ \vdots & \vdots \\ -\frac{1}{2} \left[ x^{(i)}(n-1) + x^{(i)}(n) \right] & 1 \end{bmatrix} \]

\[ Y_n = [x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)]^T \]  

The differential equation of the above whitening form is:
\[ x^{(i)}(k+1) = \left( x^{(0)}(1) - \frac{u}{a} \right) e^{ak} + \frac{u}{a} \]  

From this formula, the predicted value can be obtained. \[ X^{(i)}(K+1) \] After the first-order subtraction operation, the predicted value of the original data can be obtained.

4.3. Perform error checking

4.3.1. The formulas of residual value and relative error
\[ \Delta^0(i) = X^{(0)}(i) - \hat{X}^{(0)}(i) \]

\[ \phi(i) = \frac{\Delta^0(i)}{X^{(0)}(i)} \times 100\% \]

4.3.2. The original sequence standard deviation:
\[ S_i = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x^{(0)}(i) - \bar{x}^{(0)})^2} \]

The variance ratio: \[ C = \frac{S_2}{S_1} \]

The small error probability:
\[ p = p \left| \frac{\Delta^0(i) - \bar{x}^{(0)}}{S_1} \right| < 0.6745 S_1 \]

\[ \bar{x}^{(0)} = \frac{1}{n} \sum_{i=1}^{n} x^{(0)}(i) \]

4.4. Prediction model accuracy analysis

After the prediction model is established, the prediction accuracy test needs to be performed. Only when the calculation accuracy of the prediction model meets the requirements, it can be used. Otherwise, even if the prediction result is not in line with reality, it cannot be adopted. The calculation accuracy level is shown in Table 2 [7]

| Accuracy level          | P     | C     |
|-------------------------|-------|-------|
| First grade, excellent  | P ≥ 0.95 | C ≤ 0.35 |
| Second level, good      | 0.8 ≤ P < 0.95 | 0.35 < C ≤ 0.5 |
| Third grade, qualified  | 0.7 ≤ P < 0.8 | 0.5 < C ≤ 0.65 |
| Fourth grade, unqualified | P < 0.7 | C > 0.65 |
4.5. **GM (1, 1) prediction results**

Since the early data may affect the accuracy of the prediction model, this paper decided to use the hazardous waste production in China for the past 7 years (2011~2017) as the original data \( X_0(t) \). Generate \( X_1(t) \), build the model according to the above GM(1,1) we got

\[
x^{(1)}(k + 1) = 14238.60e^{0.1735k} - 10807.38
\]

To the prediction model, the predicted values of national hazardous waste production in each year can be calculated, as shown in Table 3.

| Years   | Raw data     | Restore data | Residual   | Relative error (\( \phi \)) |
|---------|--------------|--------------|------------|-----------------------------|
| 2011    | 3431.2200    | -            | -          | -                           |
| 2012    | 3465.2400    | 2697.3908    | -767.8492  | -22.1586                    |
| 2013    | 3156.8900    | 3208.3903    | 51.5003    | 1.6314                      |
| 2014    | 3633.5200    | 3816.1947    | 182.6747   | 5.0275                      |
| 2015    | 3976.1100    | 4539.1429    | 563.0329   | 14.1604                     |
| 2016    | 5347.3028    | 5399.0480    | 51.7480    | 0.9677                      |
| 2017    | 6936.8925    | 6421.8553    | -515.0347  | -7.4246                     |

Post-test difference analysis: According to Table 2, the posterior difference ratio \( C < 0.35 \) and the small error probability \( P \geq 0.95 \), the first-order accuracy is satisfied, the system can be predicted according to the model. [8] Table 4 shows the predicted value of China's hazardous waste production in the next five years (2019~2023).

| Year   | Hazardous waste production | Growth rate |
|--------|----------------------------|-------------|
| 2018   | 7638.42                    | 10.11%      |
| 2019   | 9085.46                    | 18.94%      |
| 2020   | 10906.63                   | 20.04%      |
| 2021   | 12953.86                   | 18.77%      |
| 2022   | 15788.93                   | 21.89%      |

Predictive model equation

\[
x^{(1)}(k + 1) = 14238.60e^{0.1735k} - 10807.38
\]

Posterior difference ratio \( C = 0.1749 \)

Small error frequency \( P = 1 \)

Model accuracy great

4.6. **Analysis of prediction results**

It can be seen from Table 4 that the annual output of hazardous wastes in the country will further increase from 2018 to 2022, with an annual growth rate of 10.11%~21.89%. As China plans to build a well-off society in 2020, it will promote economic development and will continue to grow in the next few years, and hazardous waste will also be in a period of rapid growth. By 2022, the national hazardous waste production is expected to reach 157,789,300 tons, compared with the predicted value of hazardous waste production in 2015, 27.09 million tons [6], the increase is about 482.83%. Therefore, it is far from enough to increase the environmental protection input to the west, to analyze the composition of industrial hazardous waste, to effectively classify [6] and to strengthen the management of the application registration system [9]. We should consider how to break the trans-provincial transfer barriers. And make sure the surplus area of waste resources is combined with the area where waste is over-produced.
5. Conclusions
This paper establishes the GM (1,1) model with the national hazardous waste output from 2011 to 2017 as the original data. The posterior difference ratio $C$ is 0.17, the small error frequency $P$ is 1, and the prediction accuracy satisfies the first-level requirement. It can be seen that the GM(1,1) model can better predict the change trend of hazardous waste production in the next few years. It is predicted that by 2023 China's hazardous waste production will reach 152,889,300 tons.

China's hazardous waste production shows obvious regional characteristics: industrialized areas in eastern and northwestern China account for more than 50% of hazardous waste production, but most of the disposal capacity of hazardous waste industries are concentrated in economically developed areas such as East China and North China. The government’s restrictions on the transfer of hazardous waste across provinces have further exacerbated geographical mismatches. It is recommended that the government as the guidance, production and disposal enterprises jointly help to promote the development of hazardous waste resources, thus breaking the deadlock of geographical mismatch.

The number of hazardous wastes that are increasing year by year is still insufficient. The existing treatment methods should be improved and the hazardous waste management system should be strengthened. Therefore, the comprehensive utilization efficiency of hazardous waste is improved, and it is truly "turning waste into treasure" and "turning decay into magic."

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