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Research Article

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Forecasting the emissions of sulfur dioxide during the twelfth five-year plan period in China based on grey model

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ABSTRACT

The grey system theory is an interdisciplinary scientific area, the very method of analysis and prediction using small data sets and inadequate information to achieve an effective forecast of future trends optimally and generally. In this article, the mathematical principle, derivation and application are investigated. The data of sulfur dioxide emissions nationally and regionally from 1998 to 2012, are used to compare the performances and predict the emissions in the Twelfth Five-Year Plan period. The simulation results show that grey models have higher performances not only on model fitting but also on forecasting and some useful conclusions have been drew.

Keywords: GM (1, 1) model, sulfur dioxide emissions, regional difference

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INTRDUCTION

In China, early in 1980s, Professor Deng brought forward the grey system theory [1], an applicable method to analyze unascertained situation and predict trend of certain term with poor information or few observed data [2]. And then, many scholars have developed the theory, from management information system to social system, economic system, natural system, etc. [3]. With the help of these newly emerging researches, many complicated and unaccountable problems can be explained and much foresight about the nature and environment have been brought forward. A lot of modeling practice shows that the GM (1, 1) model has better effect than the exponential curve regression model [4, 5]. A step in the right direction has been taken by lots scholars to devote to solution, or adjust the data [6, 7], or improve model [8].

No complete data before 1997, so sulfur dioxide is both a grey system and a discrete dynamic system. Based on grey system theory, this article takes the GM (1, 1) model as a new tool to be applied in environmental prediction and management. We forecast the sulfur dioxide emissions in China utilizing the provincial data from 1998 to 2011， furthermore, analyze the regional differences and reasons behind that. This article has sought to not only advance the prediction of the sulfur dioxide emissions during the Twelfth Five-Year Plan period based on grey model method and analyzing the regional differences impact on emission, but also present theoretical basis for State control planning of sulfur dioxide emissions in China.

EXPERIMENTAL SECTION

Data selection

In this study, data are selected from nation-wide and regional Statistical Yearbook from 1999 to 2013, Annual Statistic Report on Environment in China from 1998 to 2011, and the index applied to the analysis below is selected from the Focus of Regional Atmospheric Prevention and Control of the Twelfth Five-year Plan. Data of sulfur dioxide in 2012 are used to test the predicting outcomes.

Grey model rationale and mathematical derivation

In this section, we construct the traditional grey GM (1, 1) model and briefly look at the relevant basics of analysis of both parameter a and b. Assume $X^{(0)}$ is the original sequence of data, $X^{(0)} =\{x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\}$,which stands for the non-negative original historical time series data. Then indicate new generate series of data as $X^{(1)}$, and $X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\}$,. If there is a relationship between $x^{(0)}$and $x^{(1)}$ as $x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i)^{2}$ [1], it is called the first order accumulated generating operation , marked as 1-AGO, and $X^{(1)}$ is called the first order accumulating generation sequence of $X^{(0)}$.The sequence $Z^{(1)} = \{z^{(1)}(2), z^{(1)}(3), \cdots, z^{(1)}(n)\}$ demonstrates the mean consecutive neighbors generation operator for $X^{(1)}$,and $Z^{(1)}(k) =0.5[x^{(1)}(k)+ x^{(1)}(k-1)]$. The following differential equation represents the approximation of $x^{(0)}(k)$ data:

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=b \tag{1}$$

Where a and b represent estimated parameter. Then we can obtain the discretization of the Eq. (1):

$$\Delta^{(1)}(x^{(1)}(k+1))+az^{(1)}(x(k+1))=b \tag{2}$$

It can be simplified:

$$x^{(0)}(k+1)=a[-\frac{1}{2}(x^{(1)}(k)+x^{(1)}(k+1))]+b \tag{3}$$

The matrix form of Eq. (1) will be described as follow:

$$\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -\frac{1}{2}(x^{(1)}(1)+x^{(1)}(2)) & 1 \\ -\frac{1}{2}(x^{(1)}(2)+x^{(1)}(3)) & 1 \\ \vdots & \vdots \\ -\frac{1}{2}(x^{(1)}(n-1)+x^{(1)}(n)) & 1 \end{bmatrix} \tag{4}$$

The parameter matrixes are $\hat{a}=[\hat{a},\hat{b}]^T=(B^TB)^{-1}B^TY$. Plug estimated result into Eq. (2) and the time respond function of grey differential equation is:

$$\hat{x}^{(1)}(k+1)=[x^{(1)}(1)-\frac{\hat{b}}{\hat{a}}]e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}} \tag{5}$$

And we can obtain the formula with regard to original series data:

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)=(1-e^{\hat{a}})[x^{(1)}(1)-\frac{\hat{b}}{\hat{a}}]e^{-\hat{a}k} \tag{6}$$

RESULTS AND DISCUSSION

Statistical analysis of national-level

The results of GM (1, 1) demonstrate that the model generally has a good effect with a good average relative error (6.57%), which reflects the fluctuations in the system has high consistency with the sequence of data. Furthermore, we obtain the time respond function of grey model is:

$$x(k+1)=134455.5871\cdot e^{0.14877k}-13264.5871 \tag{7}$$

According to the Eq. (7), predicted sulfur dioxide emissions in 2015 is 17.02% more than that in 2010 growing at an annual rate of 4.01 %, which seems that it will be failure to achieve the emission reduction targets of the Twelfth Five-Year Plan (-10%).

As shown in Fig.1, since 1988, China's regional sulfur dioxide emissions' upper quartile, lower quartile, median and mean are slow growth, and there are small fluctuations in 2005 and 2010 respectively. On the whole, sulfur dioxide emissions consistent with the trend of economic growth, which have a rapid increase when economy grows rapidly

[1] where k=1,2,$\cdots$,n; similarly hereinafter.

and decrease at the time of economic slowdown. Even though, in the plan period, economy of China increases slower than past years, at an average annual growth of 7%, there still is a rising trend of sulfur dioxide emissions.

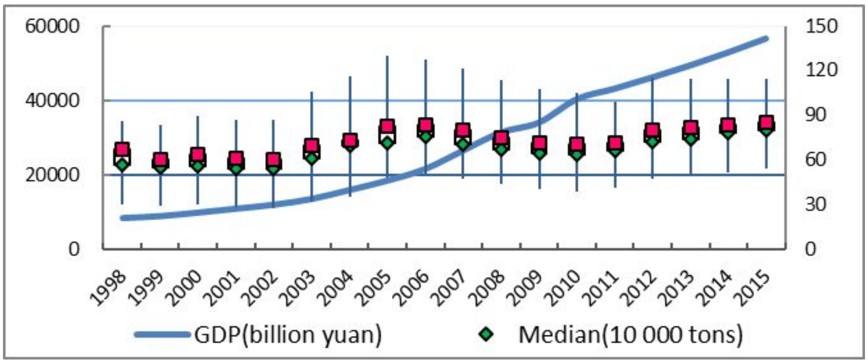

Fig.1: Sulfur dioxide emissions box plot

Regional comparative analysis

Table 1 shows the results of GM (1, 1) on provincial data from 1998 to 2011 with some data having been adjusted and revised.

Table 1 : GM (1, 1) analysis results of provincial data

	2010	2015	a	b	Average relative error (%)
Beijing	11.51	8.89	0.0617	26.4903	7.0987
Tianjin	23.52	21.29	0.0173	28.7276	5.9848
Hebei	123.38	139.34	-0.0015	135.6847	6.1420
Shanxi	124.92	142.92	-0.0076	124.9394	6.3385
Inner Mongolia	139.41	206.14	-0.0575	75.6164	18.4764
Liaoning	102.22	129.40	-0.0248	83.4235	11.3067
Jilin	35.63	47.29	-0.0350	25.5444	9.0791
Heilongjiang	49.02	69.87	-0.0527	27.6821	9.7930
Shanghai	35.81	35.56	0.0199	50.3490	12.8506
Jiangsu	105.05	113.54	0.0025	118.6468	7.7004
Zhejiang	67.83	79.63	-0.0109	65.8416	10.6224
Anhui	53.21	65.87	-0.0293	39.3945	7.4012
Fujian	40.91	60.80	-0.0587	22.1270	17.5705
Jiangxi	55.71	82.73	-0.0546	31.9352	15.7856
Shandong	153.78	168.89	0.0052	185.1550	5.6912
Henan	133.87	185.88	-0.0409	90.4979	13.4932
Hubei	63.26	75.70	-0.0173	55.8904	7.3313
Hunan	80.13	83.88	-0.0023	80.5261	7.5049
Guangdong	105.05	119.98	-0.0134	95.1525	12.4151
Guangxi	90.38	89.02	0.0103	1.3454	16.6849
Hainan	2.88	3.19	-0.0306	1.8664	7.1340
Chongqing	71.94	66.77	0.0152	86.8217	7.7243
Sichuan	113.10	114.75	-0.0006	113.6095	9.2247
Guizhou	114.88	108.65	0.0192	152.7345	4.0139
Yunnan	50.07	73.25	-0.0447	33.4508	8.9172
Tibet	0.39	0.64	-0.1464	0.0427	19.1943
Shaanxi	77.86	105.12	-0.0285	63.8456	9.4592
Gansu	55.18	71.07	-0.0398	35.3223	8.1689
Qinghai	14.34	26.37	0.1363	0.3998	22.5223
Ningxia	31.08	48.10	-0.0485	20.5566	11.7680
Xinjiang	58.85	97.72	-0.0751	25.7833	10.6393

Compared with 2010, according to the trend of sulfur dioxide emissions, there are six provinces' sulfur dioxide emissions will reduce in 2015, including Beijing(-22.70%), Tianjin(-9.46%), Shanghai(-0.69%), Guangxi(-1.51%), Chongqing(-7.19%) and Guizhou(-5.43%). In the provinces of sulfur dioxide increasing emissions, top ten provinces are Qinghai, Tibet, Xinjiang, Ningxia, Fujian, Jiangxi, Inner Mongolia, Yunnan, and Heilongjiang. Particularly, the base of sulfur dioxide emissions is too small in Tibet, as a common in the western region, which is seeing impressive growth numbers of a small base as well. As it shown in Fig.2 intuitively, the geographical distribution of sulfur dioxide in China has regional characteristic. Compared with 2010, in the western region, there is lager growth ratio of sulfur dioxide emissions than the east in 2015.

Northeast region		Eastern region				Central region		Western region			
6	Liaoning	1	Beijing	13	Fujian	4	Shanxi	5	Inner Mongolia	26	Tibet
7	Jilin	2	Tianjing	15	Shandong	12	Anhui	20	Guangxi	27	Shaanxi
8	Heilongjiang	3	Heibei	19	Guangdong	14	Jiangxi	22	Chongqing	28	Gansu
		9	Shanghai	21	Hainan	16	Henan	23	Sichuan	29	Qinghai
		10	Jiangsu			17	Hubei	24	Guizhou	30	Ningxia
		11	Zhejiang			18	Hunan	25	Yunnan	31	Xinjiang

Fig.2: Provincial sulfur dioxide emissions growth

According to the interpretation on the regional division of the national bureau of statistics of China in 2011, China can be divided into four regions: Eastern region, Central region, Western region, Northeast region shown in Table 2. The growth percentage of Eastern region is the minimum, smaller than the growth of national total level, and next in turn are Western region, Central region and Northeast region, which is similar to the conclusion of discussion above.

Table 2: Prediction of sulfur dioxide emissions of four-region in China

Region	2010	2015	annual growth rate	growth percentage
Northeast region	186.87	246.55	5.70%	31.94%
Eastern region	669.71	751.12	2.32%	12.16%
Central region	511.09	636.99	4.50%	24.63%
Western region	817.48	1007.60	4.27%	23.26%

Regional influence factor analysis

In view of economic development, the sulfur dioxide emissions emerge out significant traits of regional difference in China. The scatter diagram in Fig.3 shows that there is a two-way relationship between economic development and environmental contaminate. In the first quadrant, 10 provinces have huge economic outputs companied with the huge sulfur dioxide as well. In the second quadrant, the economic developments of these 5 provinces are relatively undeveloped, resulting in large incremental sulfur dioxide emissions. In the third quadrant, economy and sulfur dioxide emissions growth of two provinces are both relatively lower. In the fourth quadrant, their economic developments are relatively well-development, while sulfur dioxide emissions grow slowly.

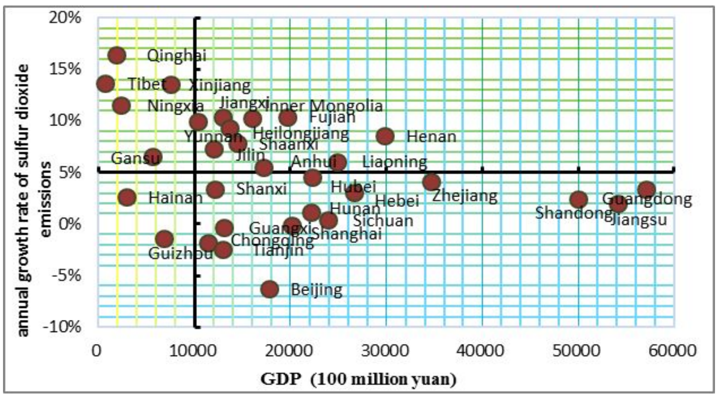

Fig.3: The relationship between GDP and sulfur dioxide emissions

Regional industrial structure can also explain part of the reason of the difference on sulfur dioxide emissions in different regions partially. As shown in the Fig.4 (a), the second industry is given priority to many provinces, which contribute and share a lot in regional economic development. In recent years, China's regional industrial transfer has been accelerated, and the heavy industry in the eastern area transfer to the central and western area gradually, especially the industry associated with energy resources. In a few provinces, the high proportion of tertiary industry make sulfur dioxide emissions at a slow increasing rate.

Pollution treatment effort is another key point for emission reduction, which depends on the investment scale and human capital in pollution control. China’s environmental governance also emerges a geographic feature, as shown in Fig.4 (b). Some undeveloped areas in west, whose environmental investment are less and environmental regulations are poor, result in more sulfur dioxide emissions.

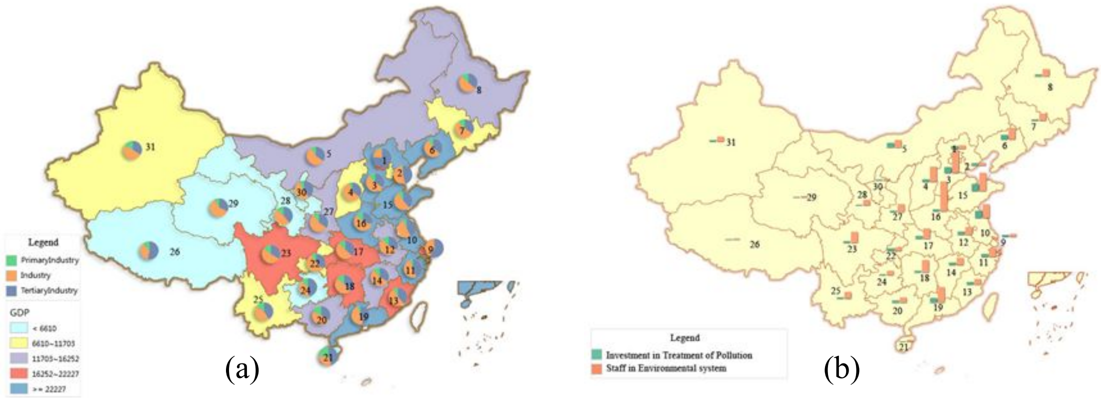

Fig.4: GDP and industrial structure and environmental protection of provinces

CONCLUSION

Based on the grey forecasting above, sulfur dioxide emissions have rising trend in the Twelfth Five-Year Plan time period, and the emission reduction targets may embrace the potential threats if we don’t attach sufficient attention.

The major contribution of this article is the description and forecast on the trends of sulfur dioxide emissions in China regionally and comparatively. From the perspective geographical issue, the east regions are predicted to have better emissions reduction than ones in west. Sulfur dioxide emissions appear regional difference, closely related to the levels of economic development and environmental governance. To achieve the emission reduction targets in the Twelfth Five-Year Plan, we should set different targets, practical measures and policies in different regions.

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