Pol. J. Environ. Stud. Vol. 23, No. 5 (2014), 1753-1762

Original Research

Evaluation of Environmental Protection Levels Using Grey Relational Analysis

Lang Wang[1, 2], Jinghua Sha[1, 2], Qier An[1, 2]*

[1]China University of Geosciences, Beijing 100083, China
[2]Software Engineering Center Chinese Academy of Sciences

Received: 17 May 2013
Accepted: 2 April 2014

Abstract

In this paper the environmental protection levels of 30 Chinese provinces are evaluated using grey relation degree analysis. The research period is from 2004 to 2011. An indicator system was built and it includes 10 indicators from 3 points of view: waste discharge, environmental remediation, and resource utilization. Evaluation has been done on both integrated and separate analysis according to 3 kinds of indicators. Result shows that there is a big difference in environmental protection levels among different provinces. The provincial Grey relation degree varies between 0.5 and 0.9. Environmental protection levels have a close relationship with economic growth. Provinces with higher GDP per capita usually have higher environmental protect level and vice versa. The environmental protection level of each province changes litter among different years. Beijing, Shanghai and Tianjin do better in waste discharge while Qinghai, Ningxia, Shanxi, and Inner Mongolia have more waste discharge. Provinces that do better in environmental rehabilitation change a lot during the research period. Beijing and Tianjin do best in resource utilization, which indicates that the energy and water consumption in these two regions are much smaller than other provinces.

Keywords: grey relation analysis, environmental protection, comprehensive evaluation, China

Introduction

China's economic development goes along with a growing number of environmental problems. In recent years the atmospheric environment and water environment are alarmed to different degrees. The Chinese government has done many efforts for environmental protection. In 2011 the State Council put forward "on the strengthening of key environmental protection work" and "Twelfth five-year plan on national environmental protection." In 2012 the 18th National Congress of the Communist Party of China incorporated the construction of ecological civilization into the overall layout of "Five in One" for the cause of socialism with Chinese characteristics, and proposed the promotion of ecological civilization and the construction of a beautiful China. Under the correct leadership of the Party Central Committee and the State Council, positive progress has been made in environmental protection work. Take the data of 2011 as an example. Compared to 2010, chemical oxygen demand emissions, ammonia emissions and sulfur dioxide emissions in 2011 fell by 2.04%, 1.55%, and 2.20%, respectively. Gratifying progresses has also been made in other fields.

However, China is large. Chinese provinces are different from each other in economic development and culture. Therefore, the environmental protection levels in Chinese provinces are unavoidably unbalanced. This fact makes an overall evaluation of provincial environmental protection necessary.

This paper tries to evaluate environmental protection levels of Chinese provinces using Grey relation evaluation, which is widely used in multi-index comprehensive evalu-

*e-mail: 280790413@qq.com

Table 1. Indicators of environmental protection levels.

Group	Indicator		Units
Waste discharge	X_1 (-)	Volume of industrial solid wastes produced per unit of GDP	Ton/10,000 yuan
	X_2 (-)	Volume of waste water discharge per unit of GDP	Ton/10,000 yuan
	X_3 (-)	Volume of Industrial Waste Gas per unit of GDP	m^3/yuan
	X_4	Utilization rate of industrial solid wastes	%
	X_5	Rate of industrial waste water meeting discharge standard	%
Environmental rehabilitation	X_6	Waste gas treatment facilities owned per 10,000 people	Sets/10,000 persons
	X_7	Wastewater treatment facilities owned per 10,000 people	Sets/10,000persons
	X_8	Rate of Environmental pollution control investment in GDP	%
Resource utilization	X_9 (-)	Energy consumption per unit of GDP	Tce/10,000 yuan
	X_{10} (-)	Water use per capita	m^3/person

"-" after indicator means this indictor is the smaller the better while the others opposite

ation. Paul used Grey relation analysis to find the relative weights of financial ratios of four companies each year and to rank the companies in the period [1]. Jiang and He introduced local Grey SVR (LG-SVR) integrated grey relational grade with local SVR for financial time series forecasting [2]. Wei finds the optimal alternative by calculating the linguistic degree of Grey relation of every alternative and 2-tuple linguistic positive ideal solution and 2-tuple linguistic negative ideal solution [3]. Zhai and Zhong prepossessed a novel method based on grey relation analysis and rough set theory to improve the effectiveness and objectivity of the design concept evaluation process [4]. Wang (2009) combined Grey relation analysis with fuzzy multi-criteria group decision-making (FMCGDM) to evaluate financial performance of Taiwan container lines [5]. Chen and his colleges developed a fuzzy AHP (fuzzy analytic hierarchy process) to determine the weighting of subjective judgments [6]. There are some other utilizations of Grey relation analysis, like the selection of the best all-around athlete [7], residential energy-saving buildings [8], the transfer efficiency of transport terminals [9], customer satisfaction of automobile 4S enterprises [10], the importance of customer attributes' for edible oil [11], selecting an outsourcing provider [12], and understanding the degree of concentration of medical resources in a specific area [13].

The authors have focused on the environmental protection level of Chinese provinces in 2010 without considering the changes among different years [14]. In this paper we built an index system to evaluate the environmental protection level and then calculated the Grey relation degree of 30 Chinese provinces between 2004 and 2011. After that, the evaluation results are discussed both on overall environmental protection as well as three second-level indicators: waste discharge, environmental rehabilitation, and resource utilization. This paper can be used to understand the environmental protection of 30 Chinese provinces and the strengths and weakness of each province, which is useful for future environmental tasks.

Data and Method

Indicator System

Broadly speaking, Environment protection refers to all of the human activities that aimed to resolve actual or potential environmental problems, coordinate the relationship between people and the environment, and ensure sustainable development of society and the economy [15]. In a narrow sense, environmental protection refers to the conscious activities of those protecting and utilizing natural resources soundly, preventing the natural environment from being polluted and destroyed, integrated improvement of polluted and destroyed environment, in order to create a suitable environment for living and working [16]. Methods of environmental protection include education, engineering technology, law, and economics [17]. The main content of environmental protection includes three aspects: pollution of production and living prevention, damage prevention, and valuable environmental protection.

Taking into consideration one of the indicator system principles of scientific, simple, feasible, objective principle, as well as the availability of data, representativeness, and independence of each indicator, 10 indicators are chosen to evaluate the environmental protection level of each province as showed in Table 1. The 10 indicators are composed of 3 groups. The first group is waste discharge, which can be evaluated by 5 indicators: volume of industrial solid wastes produced per unit of GDP (X_1), volume of waste water discharge per unit of GDP (X_2), volume of industrial waste gas per unit of GDP (X_3), utilization rate of industrial solid wastes (X_4), and rate of industrial waste meeting discharge standard (X_5).

All of the data used in this paper can be found on the official website of the National Bureau of Statistics of China (http://www.stats.gov.cn/tjsj/)

Grey Relation Model

The Grey system refers to systems with part of information known are part unknown. Grey system theory deals with systems with incomplete information and aims to predict unknown information of the system based on known information in order to understand the whole system. Grey relational analysis provides an objective criterion to measure the relation between different objects and factors. The basic idea is to determine the relation between each sequence based on the similarity of their geometry curve. The closer the curve, the bigger the relation between the two objects or factors, and vice versa.

There are 2 main applications of grey relational analysis: factor analyzing and comprehensive evaluation. This paper uses it for comprehensive evaluation. The main idea of Grey relational evaluation is to: select an ideal optimal sequence from the samples to be the reference sequence, and evaluate each objective by calculating its relation degree with the reference sequence. It is an effective and efficient method to evaluate each object by taking lots of indicators into consideration.

$$x_i = \{x_{i1}, x_{i2}, K, x_{in}\}, i = 1, 2, K, n$$

Assuming that n objects need to be evaluated (in this paper, n=30), and p indicators need to be considered (in this paper, p=10), the ith object can be described as: Considering that the unit and magnitude of each indicator might be different, origin data must be normalized before grey relational evaluation. There are many methods to normalize data while this paper uses Z-score. The calculation method of Z-score is described in equation (1), where $\overline{x}_{ij}$ is the mean of x_{ij}, and $S(x_{ij})$ is the standard deviation of x_{ij}. For convenience, data after normalization are still described as x_{ij} later.

$$x'_{ij} = \frac{x_{ij} - \overline{x_{ij}}}{S(x_{ij})} \tag{1}$$

After that, reference sequence x_0 should be created by selecting the optimal value of each indicator in the sample:

$$x_0 = \{x_{01}, x_{02}, K, x_{0p}\}$$

Actually, the reference sequence x_0 is a relatively ideal optimal sample and a comprehensive evaluation standard. If the bigger jth indicator is preferred, the x_{0j} is thus the biggest value of x_{ij} in the sample: if a smaller *j*th indicator is preferred, then the x_{0j} is the smallest value in the sample: if a moderate indicator is preferred, x_{0j} is the appropriate value of this indicator.

The Grey relational coefficient is:

$$\zeta_{ij} = \frac{\Delta(\min) + \rho\Delta(\max)}{\Delta_{ij} + \rho\Delta(\max)} \tag{2}$$

...where:

$$\Delta_{ij} = \left| x_{ij} - x_{0j} \right| \tag{3}$$

$$\Delta(\max) = \max_{1\le i\le n} \max_{1\le j\le p} (\Delta_{ij}) \tag{4}$$

$$\Delta(\min) = \min_{1\le i\le n} \min_{1\le j\le p} (\Delta_{ij}) \tag{5}$$

$\rho\in[0,1]$ (ρ=0.5 is generally used.)

Then, the Grey relational grade can be calculated by:

$$\gamma_{0i} = \frac{1}{P}\sum_{k-1}^{P} \zeta_i(\mathrm{k}) \quad \mathrm{i}=1, 2, ..., \mathrm{n} \tag{6}$$

Provincial Environmental Protection Descriptions

In this section we describe the current status of environmental protection in each province. The values of each indicator for 30 provinces are listed in Table 2 using 2011 as an example year. By this table we can know that in 2011 the industrial solid wastes produced per unit of GDP (X1) in Qinghai province is the largest, which is 7.19 tons per 10,000 Yuan. Beijing has the least value, which is only 0.07 tons per 10,000 Yuan. The largest value is the 103 folds of the least value, which shows that there is a big difference between provinces in industrial solid waste produced per unit GDP. The waste water discharge per unit of GDP (X_2) in Fujian province is the largest with a value of 10.09 tons per 10,000 Yuan. On the contrary, wastewater discharge in Beijing is the least, which is only 0.53 tons per Yuan. Industrial waste gas per unit of GDP (X_3) in Ningxia province is the largest, with a value of 4.78 m^2 per Yuan. Beijing has the least industrial waste gas per unit of GDP, which is only 0.30 m^2 per Yuan. As to utilization rates of industrial solid wastes (X_4) and rate of industrial waste water meeting that discharge standard (X_5), Tianjin is the best province since it has the highest value of these two indicators. The worst provinces for X_4 and X_5 are Liaoning and Qinghai, respectively. These 5 indicators (X_1-X_5) are measurements of waste discharge.

The indicators of X_6, X_7, and X_8 are measurements of environmental rehabilitation. The waste gas treatment facilities owned per 10,000 people (X_6) in Shanxi province is the highest with a value of 3.22 while Hainan has the lowest value at 0.57 sets per 10,000 persons. The wastewater treatment facilities owned per 10,000 people (X_7) in Shanghai is the highest and its value in Gansu is the lowest. The highest value and the lowest value are 2.50 and 0.22 sets per 10,000 persons, respectively. As to rate of environmental pollution control investment in GDP (X_8), Inner Mongolia is the best province since the rate of environmental pollution control investment in GDP in Inner Mongolia is as high as 2.76%, while other provinces are much lower. This rate in Henan is only 0.61%.

The last two indicators focus on the resource utilization of the provinces. Energy consumption per unit of GDP (X_9) in Beijing is the lowest, which is only 0.43 tce/10,000 Yuan. The energy consumption per unit of GDP in Ningxia is the highest, which is 2.05 tce/10,000 Yuan. As to water use per capita (X_{10}), Tianjin is the best province because it has the

Table 2. Provincial values of each indicator in 2011.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Beijing	**0.07**	**0.53**	**0.30**	66.52	98.60	1.47	0.25	1.31	**0.43**	180.70
Tianjin	0.15	1.75	0.79	**99.83**	**99.76**	2.83	0.71	1.55	0.67	**174.00**
Hebei	1.84	4.83	3.15	41.70	95.82	2.29	0.66	2.54	1.20	271.50
Shanxi	2.45	3.53	3.75	57.40	85.46	**3.22**	0.95	2.21	1.63	207.00
Inner Mongolia	1.64	2.74	2.09	58.09	76.63	2.74	0.41	**2.76**	1.30	745.70
Liaoning	1.27	4.07	1.43	**38.02**	91.63	2.65	0.52	1.69	1.02	330.10
Jilin	0.51	3.96	1.01	58.95	83.91	1.13	0.25	0.96	0.86	477.60
Heilongjiang	0.48	3.50	0.82	68.79	90.09	1.23	0.31	1.21	0.96	919.10
Shanghai	0.13	2.32	0.71	96.56	97.74	2.01	**2.50**	0.75	0.59	535.50
Jiangsu	0.21	5.02	0.98	95.44	97.66	2.03	0.92	1.17	0.56	705.40
Zhejiang	0.14	5.64	0.77	92.04	92.48	3.06	1.55	0.74	0.55	364.00
Anhui	0.75	4.62	1.99	81.64	96.64	0.80	0.39	1.75	0.69	494.10
Fujian	0.25	**10.09**	0.85	68.49	98.14	2.04	0.92	1.13	0.61	563.40
Jiangxi	0.97	6.08	1.38	55.44	92.70	1.13	0.66	2.06	0.59	587.40
Shandong	0.43	4.13	1.11	93.68	98.17	1.59	0.56	1.35	0.82	233.10
Henan	0.54	5.15	1.51	75.23	94.42	1.06	0.35	**0.61**	0.86	243.80
Hubei	0.39	5.32	1.16	79.08	92.04	1.28	0.92	1.32	0.84	516.70
Hunan	0.43	4.94	0.85	66.91	90.28	0.80	0.47	0.65	0.82	495.90
Guangdong	0.11	3.36	0.59	87.52	87.70	1.64	0.97	0.62	0.54	443.30
Guangxi	0.63	8.64	2.55	57.70	90.51	1.30	0.50	1.38	0.73	652.20
Hainan	0.17	2.70	0.66	47.74	95.10	**0.57**	0.34	1.11	0.63	509.50
Chongqing	0.33	3.39	0.91	78.36	93.63	1.42	0.52	2.59	0.88	299.20
Sichuan	0.60	3.82	1.10	47.32	91.06	1.17	0.51	0.67	0.94	290.10
Guizhou	1.33	3.62	1.90	52.84	69.94	0.89	0.48	1.14	1.59	276.10
Yunnan	1.95	5.31	1.97	50.35	87.50	1.36	1.05	1.34	1.07	318.00
Shaanxi	0.57	3.26	1.26	59.93	94.45	1.30	0.61	1.23	0.78	234.70
Gansu	1.30	3.93	2.57	51.23	75.69	1.28	**0.22**	1.19	1.29	479.60
Qinghai	**7.19**	5.19	3.13	56.46	**53.57**	1.93	0.31	1.57	1.91	550.50
Ningxia	1.59	9.17	**4.78**	61.24	76.65	2.69	0.62	2.73	**2.05**	1157.00
Xinjiang	0.79	4.35	1.80	54.38	62.40	2.06	0.45	2.01	1.50	**2382.90**
Maximum	**7.19**	**10.09**	**4.78**	**99.83**	**99.76**	**3.22**	**2.50**	**2.76**	**2.05**	**2382.90**
Minimum	**0.07**	**0.53**	**0.30**	**38.02**	**53.57**	**0.57**	**0.22**	**0.61**	**0.43**	**174.00**
Max/Min	**103.83**	**19.00**	**15.88**	**2.63**	**1.86**	**5.62**	**11.60**	**4.52**	**4.77**	**13.69**

Data in bold means it is the best value in this indicator among 30 provinces

lowest value, which is 174.00 m^2 per person. Water use per capital in Xinjiang province is as many as 2382.90 m^2 per person. From Table 2 we can draw this conclusion that the environmental protection indicators vary in a big degree among provinces. Therefore it is of much significance to do an overall evaluation based on these indicators for Chinese provinces.

Results

Comprehensive Evaluation

Fig. 1 shows the grey relation degree of each province in 2004-11. By this figure we can see that Tianjin, Beijing, Shanghai, Zhejiang, and Guangdong are better at environmental protection while Qinghai, Xinjiang, Guizhou, and Gansu have relatively low levels. Also, we can draw the following conclusions from Fig. 1.

Firstly, there is a large regional difference in the level of environmental protection in China. The results of Grey relation degree show that the degrees change from 0.5 to 0.9 in every year of our research period. Based on 2011 data, the best three regions in environmental protection include Tianjin, Shanghai, and Beijing. Their relation values are 0.83, 0.82, and 0.80, respectively. Qinghai, Xinjiang, and Gansu have the lowest Grey relation, which are 0.50, 0.57, and 0.56, respectively. There is a large difference between different provinces.

Secondly, the level of environmental protection showed obvious geographical characteristics. More specifically, regions with higher levels of economic development also have higher levels of environmental protection, and vice versa. In 2011, the top 5 provinces in GDP per capita are Tianjin, Shanghai, Beijing, Jiangsu, and Zhejiang, and their rank in environmental protection are 1, 2, 3, 6, and 4, respectively. On the other hand, the 5 provinces with the lowest value of GDP per capita include Guizhou, Yunnan, Gansu, Guangxi, and Anhui. Their environmental protection ranked 26, 24, 28, 25, and 12, respectively. To conclude, environmental protection level in underdeveloped regions are lower than developed regions and thus need to be strengthened.

Thirdly, the level of environmental protection in each province changes little among different years. In Fig. 1, each line fluctuates in a small range, indicating the grey relation degree of each province changing little between 2004 and 2011. Among them, the biggest change happens in Inner Mongolia. The difference between the maximum and the minimum grey relation degree is 0.12. The highest value is 0.65 in 2011 and the lowest value is 0.53 in 2004, indicating that the environmental protection level of Inner Mongolia increases significantly. Its rank changes from 30 to 19 (Table 3).

Waste Discharge

In order to know more about regional differences, we focus on 3 sub-indicators of environmental protection level: waste discharge, environmental rehabilitation, and resource utilization. Table 4 shows the rank of 30 provinces in waste discharge during the research period. A smaller number in rank indicates a higher level in waste discharge, which can be understood as little waste discharge.

Some conclusions can be found in Table 4. Firstly, the rank of each province changes little among different years. Beijing, Shanghai, and Tianjin have significant strength in waste discharge. These 3 provinces keep in the top 3 in every year, indicating that their waste discharge is less than other provinces. On the contrary, Qinghai, Ningxia, Shanxi, and Inner Mongolia have more waste discharge since they ranked in 27-30 in almost every year. Secondly, the ranks in waste discharge have a close relationship between the development patterns of provinces. Provinces that have little waste discharge are mainly big cities, while provinces having more waste discharge are regions with more natural resources, like Inner Mongolia and Shanxi.

Environmental Remediation

The second category of indicators is environmental rehabilitation. There are three indicators, namely waste gas treatment facilities owned per 10,000 people, wastewater treatment facilities owned per 10,000 people, and rate of environmental pollution control investment in GDP. As seen in Table 4, Ningxia does much better than other provinces, from 2004 to 2007 in environmental rehabilitation. After 2007, Zhejiang becomes the best province instead of Ningxia in environmental rehabilitation. It is notable that Shanxi becomes the best province in 2011 while its rank was 6 in the beginning. Also, the rank of Jiangxi also decreased a lot during the research period,

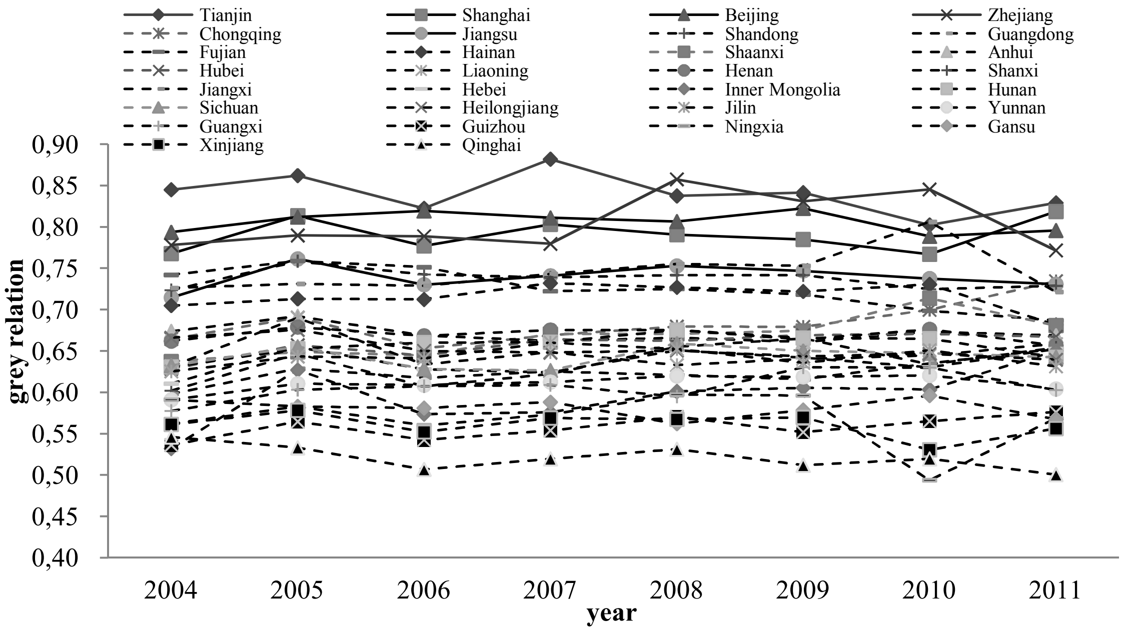

Fig. 1. Grey relation degree of each province, 2004-11.

Table 3. Rank of each province in environmental protection.

	2004	2005	2006	2007	2008	2009	2010	2011
Beijing	2	3	2	2	3	3	4	3
Tianjin	1	1	1	1	2	1	3	1
Hebei	20	17	20	21	19	19	22	18
Shanxi	21	20	24	22	17	14	21	16
Inner Mongolia	30	23	26	26	24	25	25	19
Liaoning	16	12	18	17	21	20	19	14
Jilin	19	21	17	16	18	21	16	23
Heilongjiang	11	14	14	18	20	18	18	22
Shanghai	4	2	4	3	4	4	5	2
Jiangsu	8	5	7	6	6	6	6	6
Zhejiang	3	4	3	4	1	2	1	4
Anhui	10	10	10	14	14	16	13	12
Fujian	5	6	5	9	9	9	11	9
Jiangxi	22	22	21	20	22	24	20	17
Shandong	7	7	6	7	7	7	8	7
Henan	13	13	11	10	12	15	12	15
Hubei	18	15	15	13	15	12	14	13
Hunan	17	18	12	15	11	13	15	20
Guangdong	6	8	8	5	5	5	2	8
Guangxi	25	25	23	24	26	22	23	25
Hainan	9	9	9	8	8	8	7	10
Chongqing	12	11	13	12	10	10	10	5
Sichuan	15	16	19	19	16	17	17	21
Guizhou	29	29	29	29	27	29	27	26
Yunnan	24	24	22	23	23	23	24	24
Shaanxi	14	19	16	11	13	11	9	11
Gansu	26	27	25	25	29	27	26	28
Qinghai	28	30	30	30	30	30	29	30
Ningxia	23	26	27	27	25	26	30	27
Xinjiang	27	28	28	28	28	28	28	29

which changes from 29 to 11. In other words, the environmental rehabilitation levels of Shanxi and Jiangxi have improved a lot from 2004 to 2011. Compared with other two sub-indicators, the ranks of provinces in environmental rehabilitation change a lot among years. Taking Guangdong as an example, the rank of Guangdong is 2 in 2010 while it becomes 19 in 2011.

Resource Utilization

The third indicator is the use of resources, using energy consumption per unit of GDP and water consumption per capita as indicators. Table 6 shows the rank of provinces in resource utilization from 2004 to 2011. The smaller rank indicates lower resource utilization. By Table 6, we know that Beijing is the top province in resource utilization every year, followed by Tianjin, which ranked second. That indicates these two provinces are significantly better in energy and water consumption than other provinces. Zhejiang and Guangdong ranked after Tianjin and Beijing. The ranks of each province are very stable. Xinjiang, Ningxia, Qinghai, and Inner Mongolia have big rankings in resource utilization, indicating their resource consumption is much larger than other provinces.

Table 4. Rank of each province in waste discharge.

	2004	2005	2006	2007	2008	2009	2010	2011
Beijing	1	1	1	1	3	3	3	2
Tianjin	2	3	3	3	2	1	1	1
Hebei	21	21	23	24	20	19	24	23
Shanxi	25	26	28	27	28	29	26	28
Inner Mongolia	29	28	26	26	23	24	25	22
Liaoning	20	22	24	22	24	23	19	20
Jilin	16	17	15	14	16	18	16	18
Heilongjiang	9	9	12	12	13	13	13	10
Shanghai	3	2	2	2	1	2	2	3
Jiangsu	8	6	7	5	5	5	5	4
Zhejiang	4	4	8	8	8	8	7	7
Anhui	10	10	11	15	15	14	15	14
Fujian	11	11	9	9	10	9	11	12
Jiangxi	22	20	20	18	21	20	21	19
Shandong	7	5	4	6	7	7	8	5
Henan	12	13	13	13	12	12	12	16
Hubei	15	14	14	10	11	10	9	11
Hunan	14	12	10	11	9	11	10	15
Guangdong	6	7	6	7	6	4	6	6
Guangxi	27	24	22	23	25	22	20	21
Hainan	5	8	5	4	4	6	4	9
Chongqing	13	15	16	16	14	16	14	8
Sichuan	17	16	18	19	17	15	18	17
Guizhou	30	27	27	28	26	27	28	25
Yunnan	23	23	21	21	19	21	22	26
Shaanxi	18	18	17	17	18	17	17	13
Gansu	24	25	25	25	27	25	23	27
Qinghai	26	29	29	30	30	30	29	30
Ningxia	28	30	30	29	29	28	30	29
Xinjiang	19	19	19	20	22	26	27	24

Discussion and Conclusions

This paper aims to evaluate the environmental protection level of 30 Chinese provinces from 2004 to 2011 using the Grey relation degree comprehensive evaluation method. We built an indicator system that includes 10 indicators from 3 categories: waste discharge, environmental rehabilitation, and resource utilization. Our main findings are as follows:

(1) There is a big difference in environmental protection level among different provinces. The provincial Grey relation degree varies between 0.5 and 0.9.

(2) Environmental protection levels have a close relationship with economic growth. Provinces with higher GDP per capita usually have higher environmental protection levels and vice versa.

(3) The environmental protection level of each province changes little between years. Compared with other provinces, Inner Mongolia, Heilongjiang, Jiangxi, and Shanxi change a lot. Inner Mongolia improves while Heilongjiang decreases.

(4) Beijing, Shanghai, and Tianjin do better in waste discharge while Qinghai, Ningxia, Shanxi, and Inner Mongolia have more waste discharge.

Table 5. Rank of each province in environmental remediation.

	2004	2005	2006	2007	2008	2009	2010	2011
Beijing	11	13	8	9	14	9	19	22
Tianjin	2	2	5	1	4	4	8	7
Hebei	8	10	10	8	7	12	9	5
Shanxi	5	6	3	4	2	2	3	1
Inner Mongolia	12	3	7	13	9	7	6	2
Liaoning	7	4	6	7	6	6	11	9
Jilin	22	22	18	22	24	26	23	26
Heilongjiang	20	25	23	24	20	19	24	23
Shanghai	6	7	9	5	8	13	14	4
Jiangsu	9	9	11	10	10	14	10	12
Zhejiang	4	8	2	3	1	1	1	6
Anhui	30	27	29	27	19	22	22	18
Fujian	3	5	4	6	5	8	12	13
Jiangxi	29	28	28	28	28	25	16	11
Shandong	15	12	13	16	16	15	18	16
Henan	25	23	26	25	29	30	30	29
Hubei	26	21	25	29	27	24	26	17
Hunan	27	29	27	26	25	23	29	30
Guangdong	10	18	15	12	11	17	2	19
Guangxi	18	15	17	17	17	10	13	20
Hainan	28	30	30	30	30	27	28	28
Chongqing	13	11	12	14	18	11	7	8
Sichuan	19	17	21	20	22	28	25	27
Guizhou	17	26	20	23	26	29	27	25
Yunnan	23	24	24	21	21	18	17	15
Shaanxi	16	20	14	15	15	16	4	21
Gansu	24	19	16	19	23	21	21	24
Qinghai	21	16	22	18	13	20	20	14
Ningxia	1	1	1	2	3	3	5	3
Xinjiang	14	14	19	11	12	5	15	10

(5) Provinces that do better in environmental rehabilitation change a lot during the research period.
(6) Beijing and Tianjin do best in resource utilization, which indicates the energy and water consumption in these two regions are much smaller than other provinces. The rank of each province in resource utilization is very stable.

The significance of environmental significance is self-evident. A comprehensive assessment of environmental protection levels in various regions of China is particularly important. This paper attempts to evaluate environmental protection lever by waste discharge, environmental rehabilitation, and resource utilization. Grey relation degree is used as our major method, which is suitable to do comprehensive evaluation as well as showing the changes of comprehensive level among years. However, this article has inevitable shortcomings. As an example, the indicators are independent, without considering regional differences. Hainan has the lowest number of waste gas treatment facility and we think it is the worst among 30 provinces without considering the fact that Hainan has little waste discharge. Also, the environmental protection value we calculated is relative. In other words, the results only show the relative standard among 30 provinces we considered

Table 6. Rank of each province in resource utilization.

	2004	2005	2006	2007	2008	2009	2010	2011
Beijing	1	1	1	1	1	1	1	1
Tianjin	2	2	2	2	2	2	2	2
Hebei	21	20	19	21	20	20	20	19
Shanxi	23	23	23	23	23	23	23	23
Inner Mongolia	28	27	27	27	27	27	27	27
Liaoning	20	17	17	17	17	17	17	16
Jilin	22	16	16	15	16	16	16	20
Heilongjiang	24	24	25	25	26	26	26	26
Shanghai	14	14	13	14	13	13	9	8
Jiangsu	15	15	15	16	15	15	15	15
Zhejiang	5	4	3	3	4	3	3	3
Anhui	9	9	11	9	14	14	14	14
Fujian	10	10	8	8	10	9	11	11
Jiangxi	12	11	10	12	9	11	10	12
Shandong	3	5	5	5	5	5	6	6
Henan	8	6	6	7	7	7	7	7
Hubei	19	19	21	19	22	21	21	21
Hunan	17	22	22	22	19	19	19	18
Guangdong	6	3	4	4	3	4	4	4
Guangxi	18	21	20	20	21	22	22	22
Hainan	11	8	9	11	8	8	8	9
Chongqing	4	12	14	10	11	10	12	10
Sichuan	13	13	12	13	12	12	13	13
Guizhou	26	25	24	24	24	24	24	24
Yunnan	16	18	18	18	18	18	18	17
Shaanxi	7	7	7	6	6	6	5	5
Gansu	25	26	26	26	25	25	25	25
Qinghai	27	28	28	28	28	28	28	28
Ningxia	30	30	30	29	29	29	29	29
Xinjiang	29	29	29	30	30	30	30	30

instead of absolute good or bad. In future research, the relationship between different indicators might be taken into consideration. Furthermore, regions from foreign countries can also be included in the comprehensive evaluation to obtain differences between Chinese and foreign regions.

References

1. LEE P. T. W., LIN C. W., SHIN S. H. A comparative study on financial positions of shipping companies in Taiwan and Korea using entropy and grey relation analysis. Expert Syst. Appl. **39**, 5649, **2012**.
2. JIANG H., HE W. Grey relational grade in local support vector regression for financial time series prediction. Expert Syst. Appl. **39**, 2256, **2012**.
3. WEI G. W. Grey relational analysis method for 2-tuple linguistic multiple attribute group decision making with incomplete weight information. Expert Syst. Appl. **38**, 4824, **2011**.
4. ZHAI L. Y., KHOO L. P., ZHONG Z. W. Design concept evaluation in product development using rough sets and grey relation analysis. Expert Syst. Appl. **36**, 7072, **2009**.
5. WANG Y. J. Combining grey relation analysis with FMCGDM to evaluate financial performance of Taiwan container lines. Expert Syst. Appl. **36**, 2424, **2009**.

6. CHEN M. F., TZENG G. H. Combining grey relation and TOPSIS concepts for selecting an expatriate host country. Math. Comput. Model. **40**, 1473, **2004**.
7. JIANG G.Q., YU F.L., ZHAO Y. An Analysis of Vulnerability to Agricultural Drought in China Using the Expand Grey Relation Analysis Method. Procedia Engineering. **28**, 670, **2012**.
8. XIE Y., MAO Z. Evaluation of Residential Energy-Saving Buildings Based on Grey Relational Analysis Method. Procedia Engineering. **29**, 3149, **2012**.
9. LENG Y., KOU C., ZHOU N., LI Q., LIANG Y., XU Z., CHEN S. Evaluation on Transfer Efficiency at Integrated Transport Terminals through Multilevel Grey Evaluation. Procedia - Social and Behavioral Sciences. **43**, 587, **2012**.
10. YAO C.L. Application of Grey Relational Analysis Method in Comprehensive Evaluation on the Customer Satisfaction of Automobile 4S Enterprises. Physics Procedia. **33**, 1184, **2012**.
11. TAYLAN O. A hybrid methodology of fuzzy grey relation for determining multi attribute customer preferences of edible oil. Applied Soft Computing. **13**, 2981, **2013**.
12. HSU C. C., LIOU J. J. H., CHUANG Y. C. Integrating DANP and modified grey relation theory for the selection of an outsourcing provider. Expert Syst. Appl. **40**, 2297, **2013**.
13. WU W. H., LIN C. T., PENG K. H., HUANG C. C. Applying hierarchical grey relation clustering analysis to geographical information systems – A case study of the hospitals in Taipei City. Expert Syst. Appl. **39**, 7247, **2012**.
14. WANG L., AN Q.E., SHA J.H. Environment Protection Evaluation of 30 Provinces in China Using Grey Relational Analysis. Nature Environment and Pollution Technology. **12**, 599, **2013**.
15. PENG G.W. Study of finance and taxation policies for improving environmental protection [D]. Jinan University. **2008**.
16. ZHANG W.J. On environmental protection and strengthening environmental protection measures. Friend of Science Amateurs. **11**, 156, **2011**.
17. ZHANG X.P. Theoretical analysis on the environmental protection system construction in a society [D]. Shanxi University. **2007**.