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Environment Protection Evaluation of 30 Provinces in China Using Gray Relational Analysis

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ABSTRACT

This paper evaluates the environment protection level of 30 Provinces in China using grey relational analysis based on 10 indicators which can be divided into 3 groups: waste discharge, environmental remediation and resource utilization. Evaluation has been done on both integrated and separate according to 3 kinds of indicators. Result shows that the best provinces in environment protection are Zhejiang, Tianjin and Beijing while the worst provinces are Ningxia, Qinghai and Xinjiang. The level of environment protection in the eastern coastal areas is relatively higher, and the level of environmental protection in northwest regions is relatively low. Provinces that have higher GDP per capita are likely to have higher environment protection, and vice versa. Most provinces are unbalanced in the 3 aspects and few provinces managed a full range environment protection. Cities are found to be better in waste discharge and resource utilization while resource-based provinces are on the contrary.

INTRODUCTION

China's environmental problems are becoming more and more serious nowadays. For a long time, China revealed a rapid economic growth with an average annual growth rate of 9% while the future development of China is constrained by many problems, of which the biggest problem is environment. During the past 20 years, monetary loss caused by environmental pollution shares 7%-20% of GDP, conflicts caused by environmental pollution reached 51000, only less than half among the 287 monitored cities meet the air quality standard set by the environmental protection department (Zhao 2009). Environmental problems have become one of the most restrict factors in China's economic development.

Chinese government has realized the importance of environment protection and takes a series of measures to improve the environment quality. During 1980s, the Chinese government established environmental protection as a basic national policy. In 1984, the State Environmental Protection Committee was established. In 1989, the first "environmental protection law" was promulgated. After the United Nations Conference on Environment and Development in 1992, China becomes one of the first countries to formulate and actualize the strategy of sustainable development (Shao 2009). In 1993, the Environmental Resources Committee of the NPC was formally established. Until the year of 2006, 35 laws on natural resource management, 8 lows on environment and 34 environmental protection regulations have been promulgated by the Chinese government (Liu 2009).

Environment protection issues have been studied by researchers for quite a long time after 1980s like Bezdek et al. (2006), Dukakis (1996), Verbruggen et al. (1998) and Lave (1998). Among those researches, there are some articles that evaluate environment protection, including evaluation of air quality in Spain (Baldasano et al. 2011), water quality assessment of United States (Criffiths et al. 2012), environmental impact evaluation of Vietnam (Clausen et al. 2010), the sustainability and living standard of big cities (Smook 2007), research on environment protection investment of South Welsh (Greylinga et al. 2012), policies of environment protection (Agliardi et al. 2012), and environment management problems during transition period (Cherp 2001). China's environmental protection article is mainly to evaluate the environmental protection level in certain areas, such as evaluation the energy-economic-social evaluation system of Henan province (Li 2010), evaluation of sustainable mining cities of Henan province (Zhang et al. 2012), evaluation of the Yellow River basin environment quality (Song et al. 2012), and evaluation of expansion and environment in Kunming city (Chen et al. 2009).

In comparison, environment protection related researches in China started relatively late, and regional differences in environmental protection are still evident. Therefore, this paper evaluates the environment protection level of 30 Chinese provinces in 2010 using grey relational model in order to identify the regional vitiations and features of those provinces.

CONSTRUCTION OF ENVIRONMENTAL PROTECTION 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 mankind and the environment, and ensure a sustainable development of society and economy (Peng 2008). In narrow sense, environment protection refers to the conscious activities of humans that protect and utilize natural resources soundly, prevent natural environment from being polluted and destroyed, integrate improvement of polluted and destroyed environment, in order to create a suitable environment for living and working of mankind (Zhang 2007). Methods of environment protection include education, engineering technology, law and economic methods (Zhang 2011). The main content of environment protection includes three aspects: pollution of production and living prevention, damage prevention, and valuable environment protection.

Taking into consideration 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 were chosen to evaluate the environment protection level of each province as given 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 wastewater 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). The "-" in Table 1 after indicator means that if this indictor is the smaller the better while the others opposite.

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

GREY RELATIONAL MODEL

Summary of grey relational model: Grey system refers to systems with part of information being known while part of information being unknown. Theoretic of grey system 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 of grey rational analysis is to determine the relation between each sequence based on the similarity of their geometry curve. The closer the curve is, the bigger relation between the two objects or factors, and vice versa.

There are 2 main applications of grey relational analysis: factor analysing and comprehensive evaluation. This paper uses it for comprehensive evaluation. The main idea of grey relational evaluation is that: select an ideal optimal sequence from the samples to be the reference sequence, and evaluating 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.

Construction of grey relational model: Assuming that there are *n* objects need to be evaluated (in this paper, *n*=30), and *p* indicators need to be considered (in this paper, *p*=10), thus the i[th] object can be described as:

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

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}, $S(x_{ij})$ is the standard deviation of x_{ij}. For convenience, data after normalization are still described as x_{ij} later.

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

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

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

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

The grey relational coefficient is:

$$z_{ij} = \frac{\Delta(\min) + r\Delta(\max)}{\Delta_{ij} + r\Delta(\max)} \quad ...(2)$$

Where,

$$\Delta_{ij} = \left| x_{ij} - x_{0j} \right| \quad ...(3)$$

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

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

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

Then, the grey relational grade can be calculated by:

$$g_{0i}=\frac{1}{P}\sum_{k-1}^{P}z_i(k) \quad i=1, 2, ..., n \quad ...(6)$$

ENVIRONMENTAL PROTECTION EVALUATION OF CHINESE PROVINCES

Comprehensive evaluation of 30 provinces in environment protection level can be done according to the method talked above. Firstly, the data are normalized, and then the reference X_0 is created by taking the minimum value of X_1, X_2, X_3, X_9, X_{10} and the maximum of X_4, X_5, X_6, X_7. After that, we calculate $\Delta_{ij}=\left|x_{ij}-x_{0j}\right|$ according to equation (3), and Δ (max) and Δ (min) are calculated to be 10.28 and 0.00 respectively. Then ζ_{ij} and γ_{0i} can be calculated according to equation (2). The γ_{0i} calculated is listed in Table 2.

In the comprehensive evaluation result, the best province in environment protection of China is Zhejiang province followed by Tianjin, Beijing, Shanghai and Guangdong. The worst provinces are Ningxia, Qinghai, Xinjiang, Guizhou and Gansu. A few features can be identified by Table 2 and Fig. 1.

Firstly, there are significant regional differences in the level of environment protection in China. The gray relational grade result shows that the Zhejiang has a highest grey relational grade of 0.89, while the lowest value in Ningxia is only 0.65, indicating that there is a large gap in environment protection level between different provinces.

Secondly, the level of environment protection in the eastern coastal areas is relatively higher, and the level of environmental protection in northwest regions is relatively low. According to Fig. 1, the spatial distribution of environment protection has a significant trend to be better in the east and worse in the west. Most coastal areas are green in Fig. 1, indicating that the environment protection level is quite higher than the average level (which is in yellow), while most northwest provinces are red, indicating the environment protection level is relatively lower than the average level.

Thirdly, the level of environmental protection has a close relationship to regional characteristics. More specifically, the higher developed provinces have better environment protection level, and vice versa. The top 10 areas in GDP per capita are Shanghai, Beijing, Tianjin, Jiangsu, Zhejiang in 2010, the ranking of their environment protection level is 4, 3, 2, 7 and 1 respectively. All of which are in the top five provinces except Jiangsu ranked the seventh. On the other hand, as to the 5 provinces that have lowest GDP per capita: Guizhou, Yunnan, Gansu, Anhui and Guangxi, their environment protection level ranked 27, 24, 26, 13 and 25, except Anhui relative front, the rest 4 provinces are in the bottom level. This shows that China's environment protection level in the economically underdeveloped areas needs to be strengthened.

In order to a further analysis of regional differences, we calculated the rankings of each province by focus on only one aspect among waste discharge, environmental rehabilitation, and resource utilization, which are shown in Table 3 and Figs. 2, 3, 4.

In terms of waste discharge, provinces that have relatively higher level of environment protection, are Tianjin, Shanghai, Beijing, Hainan and Jiangsu, while Ningxia, Qinghai, Guizhou, Xinjiang and Shanxi are relatively poor. To put it more concisely, province has higher level of waste discharge withdraws little waste per GDP (lower X_1, X_2, X_3) and has a relatively higher utilization rate of waste (higher X_4, X_5). Fig. 2 shows the regional distribution of waste discharge in China, where green indicates the best and red indicates the worst. As can be seen in Fig. 2, there is a strong regional feature in waste discharge: in the eastern coastal areas, the waste discharge is found to be better while in the west this indicator is relatively worse.

In terms of environmental rehabilitation, provinces that have relatively higher level of environmental protection are Zhejiang, Ningxia, Shanxi, Inner Mongolia and Tianjin, while the relatively poor provinces are Henan, Hunan, Gansu, Hainan and Jilin. To put it more concisely, provinces have a higher level of environmental rehabilitation have more waste treatment facilities (X_6, X_7) and a higher rate of environmental pollution control investment (X_8). Fig. 3 shows the environmental rehabilitation of each province in a Chinese map. We can conclude from Fig. 3 that northern provinces do best in environmental rehabilitation while middle provinces do the worst.

In term of resource utilization, provinces that have relatively higher level of environment protection are Beijing, Tianjin, Shaanxi, Shandong and Zhejiang, while the relatively poor provinces include Xinjiang, Ningxia, Qinghai, Inner Mongolia and Heilongjiang. To put it more concisely, provinces that have higher resource utilization consume little energy per GDP (lower X_9) and water per capita (lower X_{10}). Fig. 4 shows the regional distribution of resource utilization in China which indicates obviously that southern provinces do better in resource utilization than northern provinces.

Two features can be seen in Table 3 and Figs. 2, 3, 4. Firstly, most provinces are not balanced within the 3 aspects of environment protection. Few regions manage a full range

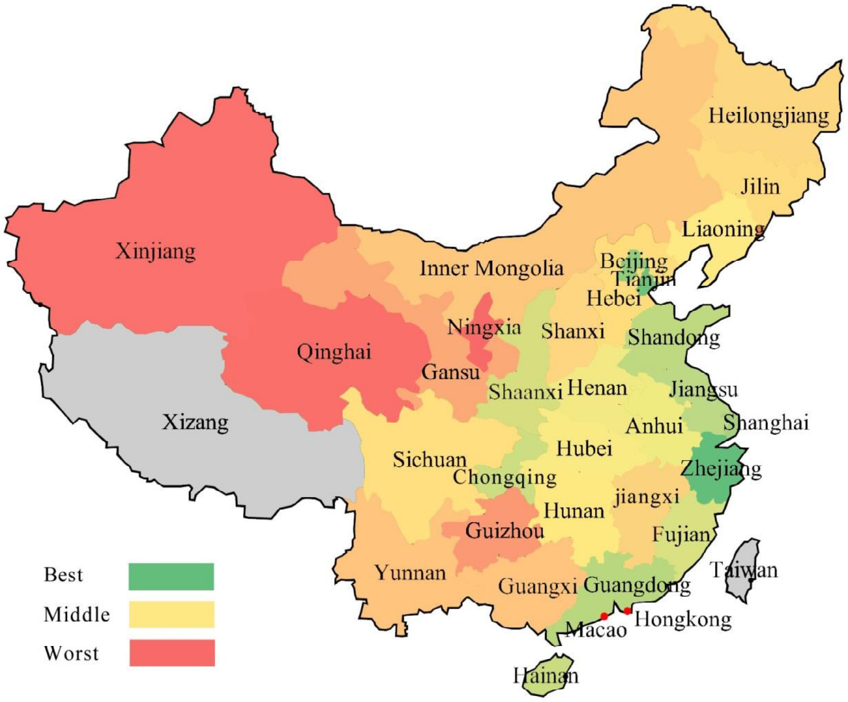

Fig. 1: Environmental protection level in 30 provinces of China.

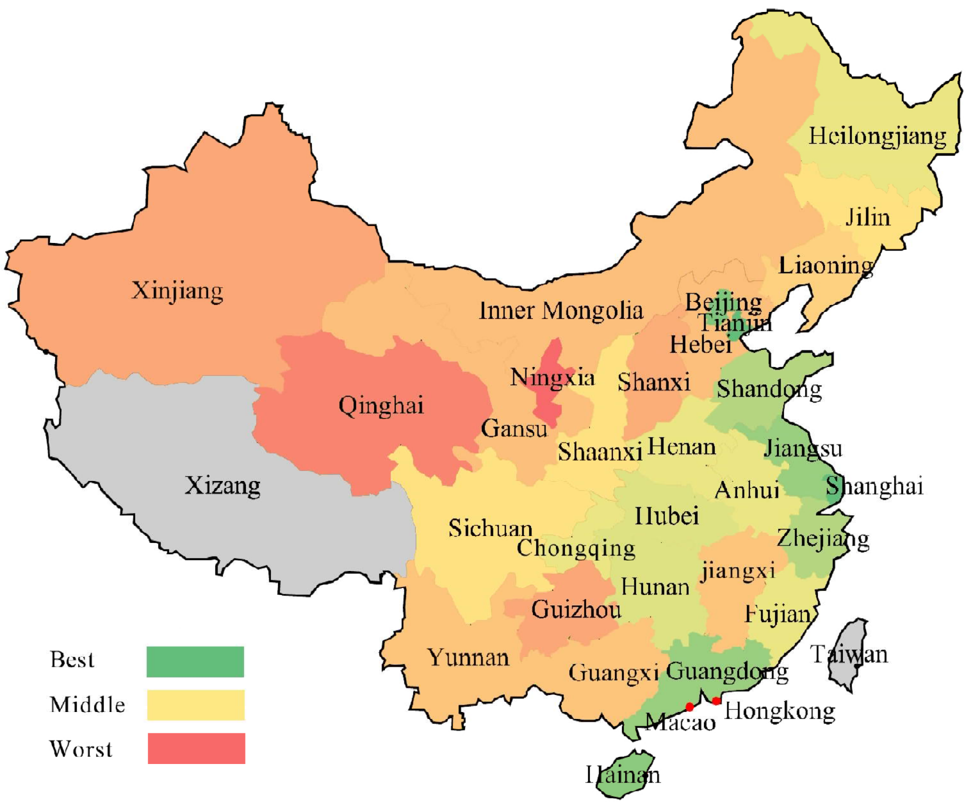

Fig. 2: Waste discharge level in 30 provinces of China.

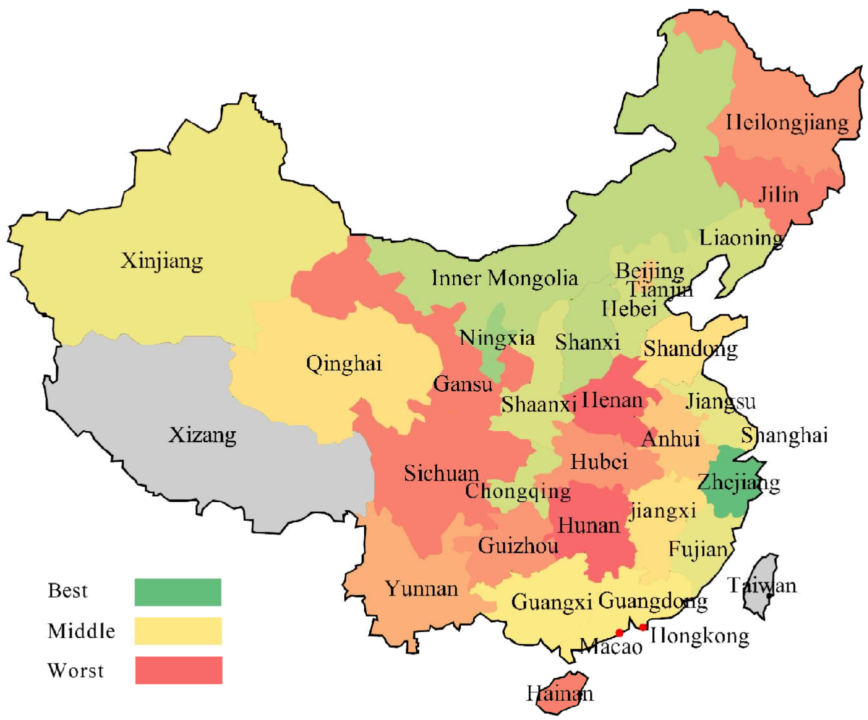

Fig. 3: Environmental rehabilitation level in 30 provinces of China.

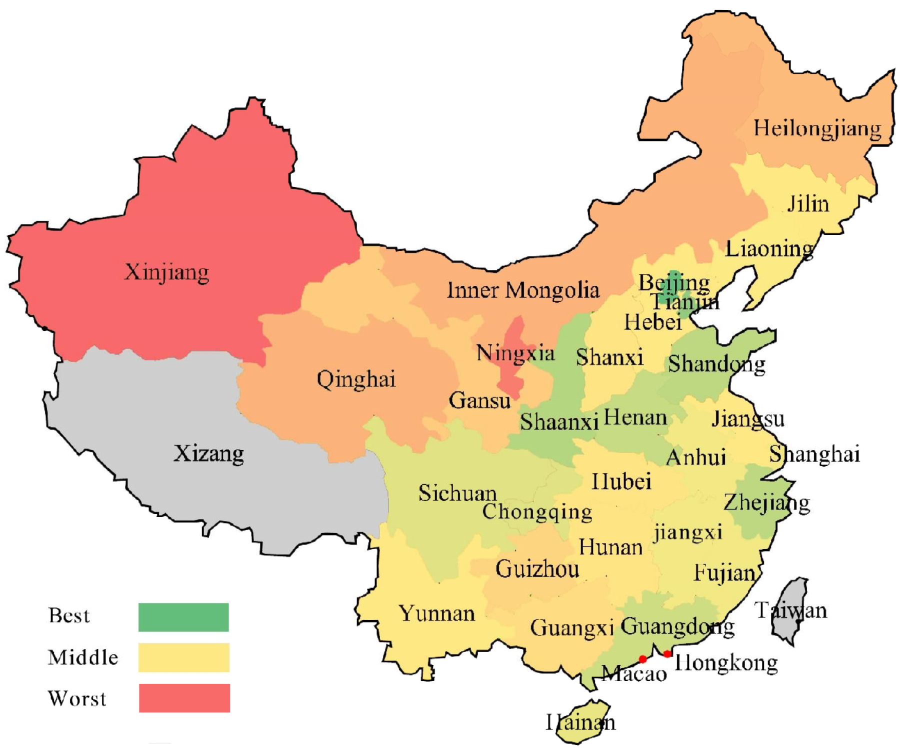

Fig. 4: Resource utilization level in 30 provinces of China.

Table 1: Indicators of environmental protection level.

Group		Indicator	Units
Waste discharge	X_1 (-)	Volume of industrial solid wastes produced per unit of GDP	Ton/10000 persons
	X_2 (-)	Volume of waste water discharge per unit of GDP	Ton/10000yuan
	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 meeting discharge standard	%
Environmental rehabilitation	X_6	Waste gas treatment facilities owned per ten thousand people	Sets/10000 persons
	X_7	Wastewater treatment facilities owned per ten thousand people	Sets/10000persons
	X_8	Rate of environmental pollution control investment in GDP	%
Resource utilization	X_9 (-)	Energy consumption per unit of GDP	Tce/10000 yuan
	X_{10} (-)	Water use per capita	m^3/person

Table 2: Evaluation results of environmental protection in China's provinces.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Evaluation	Rank
Beijing	1.00	1.00	1.00	0.74	0.97	0.58	0.55	0.69	1.00	0.99	0.85	3
Tianjin	0.96	0.92	0.95	1.00	1.00	0.70	0.66	0.73	0.90	1.00	0.88	2
Hebei	0.66	0.77	0.79	0.69	0.97	0.64	0.62	0.80	0.72	0.92	0.76	18
Shanxi	0.60	0.78	0.72	0.74	0.89	0.74	0.67	0.76	0.63	1.00	0.75	20
Inner Mongolia	0.67	0.86	0.82	0.68	0.82	0.66	0.58	0.90	0.70	0.67	0.74	23
Liaoning	0.77	0.84	0.89	0.64	0.86	0.68	0.64	0.75	0.78	0.88	0.77	15
Jilin	0.86	0.81	0.94	0.74	0.80	0.57	0.55	0.62	0.83	0.81	0.75	19
Heilongjiang	0.87	0.84	0.93	0.81	0.86	0.57	0.57	0.64	0.79	0.63	0.75	21
Shanghai	0.98	0.91	0.96	0.97	0.96	0.64	0.68	0.60	0.93	0.75	0.84	4
Jiangsu	0.96	0.74	0.96	0.97	0.96	0.60	0.72	0.65	0.95	0.68	0.82	7
Zhejiang	0.98	0.70	0.96	0.95	0.92	1.00	1.00	0.59	0.95	0.85	0.89	1
Anhui	0.81	0.76	0.89	0.87	0.96	0.54	0.58	0.71	0.89	0.79	0.78	13
Fujian	0.87	0.68	0.94	0.85	0.97	0.62	0.71	0.65	0.93	0.75	0.80	11
Jiangxi	0.76	0.70	0.93	0.64	0.88	0.55	0.60	0.73	0.93	0.76	0.75	22
Shandong	0.90	0.78	0.92	0.96	0.97	0.58	0.62	0.67	0.85	0.95	0.82	6
Henan	0.88	0.74	0.93	0.82	0.94	0.55	0.57	0.57	0.84	0.95	0.78	12
Hubei	0.89	0.76	0.94	0.84	0.93	0.55	0.58	0.63	0.83	0.78	0.77	14
Hunan	0.91	0.76	0.94	0.85	0.88	0.54	0.60	0.57	0.84	0.78	0.77	16
Guangdong	0.99	0.83	0.98	0.92	0.87	0.57	0.73	0.59	0.96	0.80	0.82	5
Guangxi	0.83	0.50	0.88	0.75	0.94	0.58	0.61	0.68	0.87	0.71	0.74	25
Hainan	1.00	0.88	0.97	0.86	0.95	0.52	0.57	0.65	0.93	0.77	0.81	8
Chongqing	0.91	0.77	0.89	0.84	0.89	0.57	0.61	0.88	0.82	0.90	0.81	9
Sichuan	0.83	0.77	0.91	0.68	0.93	0.55	0.62	0.57	0.80	0.92	0.76	17
Guizhou	0.62	0.87	0.83	0.66	0.66	0.54	0.61	0.62	0.64	0.91	0.70	27
Yunnan	0.70	0.82	0.88	0.66	0.84	0.57	0.60	0.64	0.76	0.89	0.74	24
Shaanxi	0.83	0.81	0.90	0.68	0.95	0.56	0.88	0.61	0.85	0.96	0.80	10
Gansu	0.77	0.84	0.88	0.64	0.72	0.56	0.56	0.62	0.70	0.79	0.71	26
Qinghai	0.69	0.73	0.77	0.62	0.52	0.62	0.54	0.70	0.62	0.75	0.66	29
Ningxia	0.67	0.57	0.49	0.69	0.67	0.67	0.63	1.00	0.57	0.54	0.65	30
Xinjiang	0.82	0.80	0.87	0.64	0.51	0.61	0.60	0.74	0.69	0.33	0.66	28

of environmental protection. For instance, Beijing's waste discharge and resource utilization are relatively better while the environmental rehabilitation is quite poor ranking 20. Ningxia can be another example, its level of environmental rehabilitation rank second in the country, while waste discharge and resource utilization is in the country's most backward ranking f 30 and 29 respectively. Secondly, waste discharge and resource utilization in urban areas are significantly better than other provinces. This might be a result of cities' main industries which consume little resources and earn much money, like service industries and high-tech industries. Thus, the volume of wastes discharged per unit of GDP and resource consumption per unit of GDP turn to be relatively lower. Secondly, the resource-based provinces are in the opposite since rank former in environmental rehabilitation, such as Shanxi, (rank of three aspects are 26, 3 and 20), Inner Mongolia (rank of three aspects are 25, 4 and 27), Hebei (rank of three aspects are 23, 7 and 17), and Ningxia

Table 3: Evaluation results of WD, EH and RU.

	WD	Rank of WD	EH	Rank of EH	RU	Rank of RU
Beijing	0.94	3	0.61	20	1.00	1
Tianjin	0.96	1	0.70	5	0.95	2
Hebei	0.77	23	0.69	7	0.82	17
Shanxi	0.74	26	0.72	3	0.81	20
Inner Mongolia	0.77	25	0.72	4	0.69	27
Liaoning	0.80	19	0.69	6	0.83	15
Jilin	0.83	17	0.58	26	0.82	18
Heilongjiang	0.86	14	0.59	22	0.71	26
Shanghai	0.96	2	0.64	13	0.84	12
Jiangsu	0.92	5	0.66	11	0.82	19
Zhejiang	0.90	8	0.86	1	0.90	5
Anhui	0.86	15	0.61	19	0.84	14
Fujian	0.86	11	0.66	10	0.84	13
Jiangxi	0.78	20	0.62	16	0.84	11
Shandong	0.90	7	0.62	18	0.90	4
Henan	0.86	12	0.57	30	0.89	6
Hubei	0.87	9	0.59	24	0.81	22
Hunan	0.87	10	0.57	29	0.81	21
Guangdong	0.92	6	0.63	14	0.88	7
Guangxi	0.78	22	0.63	15	0.79	23
Hainan	0.93	4	0.58	27	0.85	10
Chongqing	0.86	13	0.69	8	0.86	8
Sichuan	0.83	18	0.58	25	0.86	9
Guizhou	0.73	28	0.59	23	0.77	24
Yunnan	0.78	21	0.60	21	0.82	16
Shaanxi	0.83	16	0.68	9	0.91	3
Gansu	0.77	24	0.58	28	0.75	25
Qinghai	0.67	29	0.62	17	0.69	28
Ningxia	0.62	30	0.77	2	0.56	29
Xinjiang	0.73	27	0.65	12	0.51	30

Note: WD refers to waste discharge, EH refers to environmental rehabilitation, RU refers to resource utilization.

(rank of three aspects are 30, 2 and 29). This may be a result of the greater pressure of environmental rehabilitation in resource-based provinces leading to more investment and funds in environmental rehabilitation. Further, resource-related industries are likely to be resource-consuming with more waste discharge so that the waste discharge indicators and resource utilization indicators in resource-based provinces are poor.

DISCUSSION AND CONCLUSION

This paper evaluates the environment protection level of 30 provinces in China. The evaluation indicator system includes 10 indicators that can be divided into 3 groups: waste discharge, environmental rehabilitation and resource utilization. Our main results are:

1. Regional variations in environment protection exist among Chinese provinces. The best provinces are Zhejiang, Tianjin and Beijing, while the worst provinces are Ningxia, Qinghai and Xinjiang.
2. The level of environment protection in the eastern coastal areas are relatively higher, the level of environmental protection in northwest regions is relatively low.
3. There is a strong relationship between the level of environment protection and level of local economy. Provinces that have higher GDP per capita are likely to have higher environment protection, and vice versa, indicating that environment protection in economically underdeveloped areas ought to be strengthened.
4. Besides comprehensive evaluation, this paper measures the environment protection level by focusing waste discharge, environmental rehabilitation and resource utilization separately. The result shows that most provinces are unbalanced in the 3 aspects and few provinces managed a full range environmental protection.
5. Cities are better in waste discharge, resource utilization and worse in environment rehabilitation. On the contrary, resource-based provinces are better in environmental rehabilitation and worse in waste discharge and resource utilization. This result indicates that environmental remediation is a potential direction of cities' environment protection while resource-based provinces need to

put attention on waste discharge and resource utilization.

Based on the above results, the following recommendations are given: Firstly, cooperation mechanisms on environment protection should be built across provinces. As the grey relational analysis shows, there are big regional variations among different provinces, therefore, cooperation mechanism between different levels of the government is in need to achieve the balanced development of all regions.

Secondly, more support should be taken in economically undeveloped areas in order to increase the environment protection level of those provinces. The result shows that the environment protection level in relatively backward areas is lower than the developed areas, showing that there is a lack in environmental management for economically undeveloped areas. Generally, the main aim for local government in China is economic growth, which is represented by GDP. Therefore, the economically undeveloped areas have heavier pressure to develop its economy while putting little consciousness on local environment protection. To resolve this contradiction, more financial support and propaganda should be taken to increase the environment protection level in economically undeveloped provinces.

Thirdly, the developed model and industrial structure should be improved in resource-based area. Our result shows that the environment protection level in resource-based provinces is very low compared with other provinces of China, especially for waste discharge and resource utilization indicators. This is a result of the resource-based developed model and the big share of high resource consumption industries in those provinces. According to H. F. Zhang's research, 1% increase in the proportion of high-tech industry and 1% decrease in the proportion of high-energy-consuming industry will lead to a 1.3% reduction in the energy consumption per unit of GDP (Zhang 2008). Thus, the change of developed model and industrial structure in resource-based provinces will promote its environment protection level.

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