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Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 04

August 2016, P.P.1689-1694

Study on the Evaluation of Water Ecological Civilization–A Case of Cities in the Pearl River Delta Region of China

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Abstract: Based on balanced-score card, this paper constructs an evaluation system of water ecological civilization. Specially, the system consists of four dimensions including water ecological performance, water public service, water administration service, and study & growth. On this basis, we employ information entropy theory to judge the weights of the evaluation system and set-pair method to assess the level of water ecological civilization of cities in the Pearl River Delta. The results demonstrate that, firstly, there are significant differences of water ecological civilization development among the Pearl River Delta cities. Secondly, Shenzhen earns the highest scores while Jiangmen scores the lowest. Thirdly, the key of improving water eco-civilization is not restricting economic development, but maintaining a balanced promotion among water ecological performance, water public service, water administration procedure, and learning & growth.

Keywords: *Water Ecological Civilization, Pearl River Delta, Set-pair Analysis Method, Information Entropy*

1. Introduction

With the intensification of global warming, resource exhaustion, and other ecological problems, sustainable development becomes the first priority for human beings. On this basis, China responses and proposes a national strategy named ecological civilization construction.

As known to all, water is the source of life, the key of production, and the basis of ecology. Water ecological civilization is a core part of ecological civilization. The evaluation of water ecological civilization is significant for guiding water environmental protection. Although existing literatures have involved in this topic [1], there are still some research gaps: first, researchers are prone to use archival data while ignores the importance of questionnaire data in evaluating culture, organization, and institutional issues. Second, most of the existing indicators focus on the ecological value of water while ignore its economic value. Third, existing evaluation method is too simple to have a robust consequence. To fix these limitations, based on balanced-score card, this present paper constructs an indicator system for evaluating water ecological civilization. Then, information entropy theory is employed to judge the weight of indicators. The set-pair method, in turn, is employed to evaluate the status of water ecological civilization construction in the Pear River Delta cities. Finally, this paper proposes relevant policy suggestions for practice.

2. The indicator system of water ecological civilization based on the balanced-score card

2.1. Balanced-score card and water ecological civilization

Balanced-score card which is first proposed by Kaplan and Norton is an evaluation method for organizational strategy [2]. For the public works, the idea of balance presented by balanced-score card plays an important role in promoting public management performance [3].

To achieve water ecological civilization, a series of works on society, economy, culture, and natural environment is demanded around water. In this process, keeping balance of multiple targets would be of great necessity. Hence, balanced-score card is suitable to evaluate the level of water ecologic civilization. However, the traditional dimensions of balanced-score card such as financial, customer, internal business processes, and learning & growth need to be further reformed and adjusted according to the strategic theme, action guidance, organization need, and balance of commonweal and profitability of water ecological civilization. On this basis, we construct a model of evaluation system for water ecological civilization based on balanced-score card (see Figure 1).

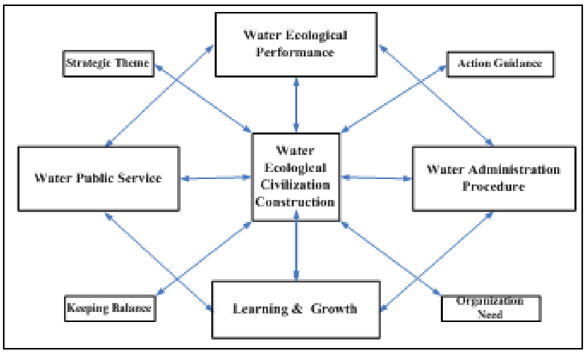

Figure 1: *The model of evaluation system for water ecological civilization based on balanced-score card*

2.2. Construction of indicator system

Based on above-mentioned model, this study reference to relevant researches [4,5] and constructs a water ecological civilization indicator system which consists of water ecological performance, water public service, water administration procedure, and learning & growth (See Table 1).

Table 1: *The indicator system of water ecological civilization*

System Layer	Weight	Subsystem Layer	Index Layer	Weight
Water Ecological Performance	0.458	Water Resources Utilization	Water Quantity Security	0.076
			Stability of Water Supply	0.113
			Water Quality	0.142
			Public Water Quality Sensitivity	0.021
			Water-saving Performance	0.035
			Water-saving Culture	0.017
		Flood Control and Disaster Reduction	Physical Damage Reduction for Flood	0.052
			Invisible Damage Reduction for Flood	0.038
		Water Environment and Ecological Protection	Pollution Abatement	0.201
			Water Damage Restoration	0.132
			Water Protection Culture	0.025
			Restoration of Biodiversity	0.031
			Water and Soil Conservation	0.012
		Industrial Development	Water Industry Development	0.076
			Industrial Structure Optimization	0.029
Water Public Service	0.215	Public Satisfaction	Satisfaction of Water Protection of the Public	0.174
			Satisfaction of Water Security of the Public	0.101
			Satisfaction of Water Resource Allocation of the Public	0.028
			Satisfaction of Water Policy of the Public	0.132
			Satisfaction of Water Culture of the Public	0.099
		Public Democratic Participation	Democratic Participation Culture of the Public	0.036
			The Degree of Broad Public Democratic Participation	0.054
			The Openness of Public Democratic Participation Information	0.112
			Full Course of Public Democratic Participation	0.045
		Balance of Water Relevant Benefits	The Balance of Short-term and Long-term Development	0.061
			The Benefit Balance between Different	0.053

			Regions	
			The Benefit Balance between Different Stakeholder Groups	0.105
Water Administration Procedure	0.189	Water Policy and Regulation System	Policies and Regulations	0.247
			The implementation of Policies and regulations	0.125
		Water Administration Regime Reform	Water Resources Management Mechanism	0.032
			Institution Construction for Water Conservancy Management	0.054
			Water Conservancy Development Mechanism	0.068
			Coordination of Water Related Organization	0.019
		Water Management Level	Water Conservancy Project Management	0.155
			Water Conservancy and Implementation Ability	0.116
			Effective Availability of Water Conservancy Investment	0.143
			Water Ecological Civilization Culture Management	0.041
Learning & Growth	0.138	Talent	Reserve of Talents	0.082
			Talents Selection	0.113
			Talent Training	0.146
			Satisfaction of Talents	0.065
		Culture	Study Platform Construction	0.218
			Study Atmosphere Construction	0.205
		Innovation	Management Innovation	0.087
			Technology Innovation	0.084

2.2.1. Water ecological performance

This present paper believes that water ecological civilization focus on not only environment, but also the complex of society, economy, and culture. In this way, the performance of water ecological civilization would be the combination of water resources utilization, flood control and disaster reduction, water environment and ecological protection, and industrial development.

2.2.2. Water public service

Water public service makes up for the ignorance of sociality of water ecological civilization. It evaluates the extent of public participation and satisfaction for the construction of water ecological civilization. Harris et. al [6] and Guha et. al. [7] consider the dimension of public service includes public satisfaction on infrastructure, attitude of government service, environment, and organizational learning. Although the content of water public service is not clear yet, we can still reduce this dimension into three basic sections which are public satisfaction, public democratic participation, and balance of water relevant benefits.

2.2.3. Water administration procedure

Within water ecological civilization construction, water administration procedure plays a key role in fulfilling national missions, enhancing satisfaction of the public, and improving social and economic performance of water conservancy projects. Indicators of water administration procedure represent the value orientation of water administration organization. According to the understanding of administration procedure in existing literatures, this paper suggests the dimension includes water policy and regulation system, water administration regime reform, and water management level.

2.2.4. Learning & growth

Learning & growth is a key driver for sustainable development of water ecological civilization. This dimension emphasizes that the present and future of water ecological civilization are equally important. With the development of learning & growth, the whole society can avoid short-term and opportunism behaviors. Following existing researches, learning & growth dimension contains the talent, culture, and innovation.

3. Research methods

3.1. Method of weighting evaluation system

In the light of the information theory [8], entropy can be considered as the measure for uncertainty of a random event of information. The steps are described as follows:

Assume m objects are needed to be evaluated (i=1, 2, …, m). Each object has n evaluating parameters (j=1, 2, … , n). In this way, we can obtain an original matrix X.

For the efficiency type index, we can obtain a normalized function:

$$X'_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (1)$$

While for the cost type index:

$$X'_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (2)$$

In this way, we can obtain a standard-grade matrix X'.

Then, the ratio of indicator value of the j parameter in i object is:

$$P_{ij} = y_{ij} \Big/ \sum_{i=1}^{m} y_{ij} \quad (3)$$

Then, we calculate the information entropy Ei, the formula is as follows:

$$E_i = -1 \Big/ \ln(m) \sum_{i=1}^{n} \frac{q_{ij}}{q_j} \ln\left(\frac{q_{ij}}{q_j}\right) \quad (i=1, 2, \ , m; j=1, 2, \ , n) \quad (4)$$

On this basis, we can employ below formula to test entropy weight Qi :

$$Q_i = (1 - E_i) \Big/ \left(n - \sum_{i=1}^{n} E_i\right) \quad (i=1, 2, …, m) \quad (5)$$

3.2. Set-pair analysis evaluation

Following current researches [9], the set-pair analysis method is fitable for application on evaluating the status of multiple target activities. On this basis, we establish a set-pair analysis evaluation model for assessment of water ecological civilization of cities in the Pearl River Delta region.

Suppose there are n objects to be evaluated form a set of $E=\{e_1, e_2, …, e_n\}$ hereinto, e_n is the nth object. Each evaluated object has m evaluation indicators $F=\{f_1, f_2, …, f_m\}$, and f_m represents the m th indicator. d_{uj} (i=1,2,…,n; j=1,2,…,m) refers to the value in the evaluation matrix. Then, according to the set pair analysis, we get a multi-target evaluation matrix Q:

$$Q = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \quad (6)$$

By comparing and choosing the value in the matrix Q, we extract the optimal evaluation set $U=[d_{u1}, d_{u2}, …, d_{un}]^T$ which contains optimal evaluation indicators within all evaluation plans. In this set, d_{uj} refers to the c_{pk} th index value in the optimal evaluation set $U=[d_{u1}, d_{u2}, …, d_{un}]^T$.In a similar vein, we also get the worst evaluation set $V=[d_{v1}, d_{v2}, …, d_{vn}]^T$. And, d_{vj} represent the value of indicator c_{pk} within the worst evaluation set.

In order to obtain the similar degree matrix A and the set $[U, V]$ unweighted, the evaluation index value w_p and the corresponding optimal value d_{uj} would be compared and treated.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (7)$$

In the similar way, we get the opposite degree matrix B and an unweighted set.

$$B = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{m1} & b_{m2} & \dots & b_{mn} \end{bmatrix} \quad (8)$$

If d_{ij} is a positive indicator,

$$\begin{cases} a_{ij} = \dfrac{d_{ij}}{d_{uj} + d_{vj}} \\ b_{ij} = \dfrac{d_{uj} d_{vj}}{d_{ij}(d_{uj} + d_{vj})} \end{cases} \quad (9)$$

If d_{ij} represents a negative indicator,

$$\begin{cases} a_{ij} = \dfrac{d_{uj} d_{vj}}{d_{ij}(d_{uj} + d_{vj})} \\ b_{ij} = \dfrac{d_{ij}}{d_{uj} + d_{vj}} \end{cases} \quad (10)$$

Combining with weights from information entropy $W=(w_1, w_2, w_m)$, similar degree matrix A would be upgraded into weighted similar degree matrix A_w. The set $[U, V]$ can be obtained as follows:

$$A_w = W \times A = (w_1 \ \ w_2 \ \dots \ w_m) \times \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} = (a_1, a_2, \dots, a_n) \quad (11)$$

a_j represents the similar degree of the j th object in the formula (11).

In the similar way, the weighted opposite degree matrix B_w of the objects and the set [U, V] would be obtained.

$$B_w = W \times B = (w_1 \ \ w_2 \ \dots \ w_m) \times \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{m1} & b_{m2} & \dots & b_{mn} \end{bmatrix} = (b_1, b_2, \dots, b_n) \quad (12)$$

b_j is the opposite degree of the j th object in the formula (12).

Then we calculate the relative closeness degree of each objects. r_j represents the relative closeness degree of the j th object and the optimal evaluation which is calculated as follows:

$$r_j = \frac{a_j}{a_j + b_j} \quad (13)$$

Then we get the relative closeness degree matrix R:

$$R = (r_1, r_2, \dots, r_m) \quad (14)$$

In this matrix, the object which is closer to the optimal plan would have a bigger r_j value. Then the object with a bigger r_j value would have a higher ranking among all objects evaluated.

4. Sample and Data

Pearl River Delta named “the south gate of China” neighbors Hongkong and Macao. The delta embraces nine cities including Guangzhou, Shenzhen, Foshan, Dongguan, Zhongshan, Zhuhai, Jiangmen, Zhaoqing, and Huizhou. There are several world-class bases for advanced manufacturing and modern service industries. According to the report released by World Bank, until 2015, the Pearl River Delta surpasses Tokyo in Japan to become the largest urban agglomeration in the world. In this process, the local water ecological environment was heavily damaged. Hence, to obtain sustainable development, the construction of water ecological civilization is pivotal for the cities in Pearl River Delta. Concerning this issue, it is very significant to evaluate the level of water ecological civilization construction within this region.

In the present research, we used questionnaire to collect data via e-mail, online survey, and face-to-face interview. The cities in the Pearl River Delta were considered as research objects. We distributed 50 questionnaires to each city for a total of 450. This procedure yielded a response rate of 58.2% (262 respondents). In addition, 10 point system was used to evaluate each item in the scale.

5. Results

Table2 shows the evaluation results of the water ecological civilization of cities in Pearl River Delta.

Table 2: *Evaluation results of system layer of water ecological civilization*

	Water Ecological Performance	Water Public Service	Water Administration Procedure	Learning & Growth
Guangzhou	0.4736	0.6023	0.6212	0.6071
Shenzhen	0.5802	0.5969	0.5983	0.6322
Foshan	0.4523	0.6117	0.5722	0.4998
Dongguan	0.4719	0.5228	0.4284	0.4351
Zhongshan	0.5387	0.5651	0.5382	0.5857
Zhuhai	0.5352	0.5522	0.4775	0.5385
Jiangmen	0.4615	0.493	0.3926	0.5011
Zhaoqing	0.4489	0.5872	0.5203	0.5525
Huizhou	0.6031	0.6285	0.5005	0.5024

Following the results in the table, cities located in the east coast of Pearl River such as Huizhou and Shenzhen have a better water ecological performance than the west cities including Zhaoqing and Foshan. It is because the technology-intensive industry located in the east while the labor-intensive manufacture located in the west. In terms of water public service, Huizhou, Foshan, and Guangzhou occupy the top three. That is to say, in these cities, the local people would have higher-level participation rate, and governments pay more attention on water ecological service. With respect of water administration procedure, economically developed cities such as Guangzhou and Shenzhen score higher than the Jiangmen and Dongguan with a relative lower economic performance do. We indicate that the willing of economic development may lead to distraction from ecological administration of government. Finally, the results of learning & growth show that Shenzhen, Guangzhou, and Zhongshan are comparatively successful on talent cultivation in Pearl River Delta cities.

Built on the assessment results of system layer, we employed set-pair analysis method again to evaluate comprehensive performance of water ecological civilization of cities in Pearl River Delta (see figure 2).

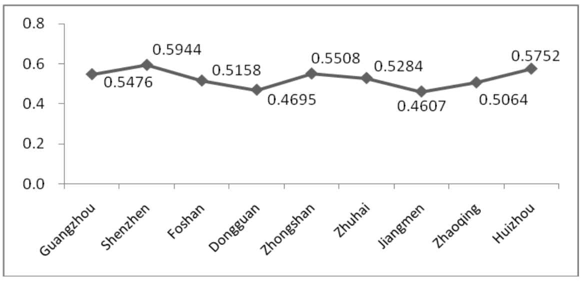

Figure 2: *Comprehensive evaluation results of water ecological civilization of cities in Pearl River Delta*

As can be seen from the line chart in figure 2, the cities in Pearl River Delta have relatively high level of water ecological civilization in general. Figure 2 also demonstrates that there are significant differences among cities. Specifically, the performances of cities located on the east coast are almost better than those of eastern cities. Hereinto, Shenzhen scores the highest with 0.5944 while Jiangmen is the last one merely with 0.4607. On this basis, we further figure out that water ecological civilization is a comprehensive characteristic that consists of four dimensions which includes water ecological performance, water public service, water administration service, and study & growth which call for a balanced development with economy, society, and ecosystem.

6. Conclusion

This present paper employs balanced-score card to form an indicator system for assessment of water ecological civilization. Then, set-pair analysis and information entropy are used to evaluate the status of water ecological civilization of Pearl River Delta cities. The main findings are as follows:

(1) The cities in Pearl River Delta have significantly different presentations on water ecological performance, water public service, water administration service, and study & growth. Specifically, east coast cities of Pearl River Delta have better water ecological performance than western cities do. Huizhou, Foshan, and Guangzhou occupy the top three in the evaluation of water public service. In terms of water administration service, the cities with better economic performance such as Guangzhou and Shenzhen score higher. There is a similar result in the rank of study & growth.

(2) Overall, the degree of water ecological civilization of Pearl River Delta cities is relatively high while demonstrating spatial heterogeneity. In the developed cities, although water ecology have been damaged by industry development, they still can rely on the restructuring industry, optimizing administration, promoting service, and enhancing talent training to obtain high level of water ecological civilization. As to those cities with relatively laggard economies, their situations of water ecological civilization are not always better than those of developed ones. That is because water ecological civilization is a comprehensive system containing economy, society, and ecosystem which need balanced development of nature, service, management and education.

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