CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651165

An Evaluation Research into Sustainable Development of Water Resources in Lakes Watershed

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As a combination of subjective evaluation and objective computation, grey clustering method was used for assessing sustainable development of water resources in lakes watershed (SWRDWLB, for short) in the paper. It was aimed for prediction and risk control on SWRDWLB. The paper studied SWRDWLB by means of analyzing various influential factors, establishing an evaluation system, and determining evaluation index weights with the help of analytic hierarchy process as well. Grey clustering method was applied to analyzing whitenization weight function and grey clustering coefficients concerning evaluation indices of SWRDWLB, so that the comprehensive evaluation grade could be further decided.

1. Introduction

Lakes watershed is characterized by eco-service functions of flat landforms, fertile soils, accessible water resources, and qualified aquatic environments. However, rapid regional economic development and man-made lake destruction spark such problems as water quality deterioration, lake eutrophication, water ecology damage, water resource shortage, and water environment pollution. These problems further result in water waste, low water usage rate, and delay in sewage treatment. (Chen and Jun, 1999) Currently, to research on innovation and evaluation models of SWRDWLB has become a strategic issue with respect to integrated management of lakes watershed. Results obtained from the above models contribute to realizing SWRDWLB and water environment improvement, and promoting social and economic development around lakes watershed as well. (Wang and Huggins, 2005). The present research focus for sustainable development has been diverted to quantitative assessment. Mainstream evaluation systems can be classified into two types: systematic index system and signal index system. For evaluation on SWRDWLB, researchers discussed principles of index selection, and built up corresponding index systems on the basis of index system framework patterns. They also devised methods of quantitative computation, including fuzzy pattern recognition, multi-attribute decision making models, fuzzy evaluation, composite measures, input-output models, and genetic algorithm. Meanwhile, management policies and codes regarding SWRDWLB were proposed by them. (Kondratyev et al., 2002)
Based on previous researches, the author undertook evaluation analysis on influential factors of SWRDWLB and determined corresponding evaluation indices. The evaluation index system was built up, and the evaluation index weights were decided with the help of analytic hierarchy process as well. Finally, according to data collection in that way, the grey classification of SWRDWLB was obtained.

2. The evaluation system of SWRDWLB

2.1 SWRDWLB analysis

Given the large number of factors to consider during the evaluation of SWRDWLB, the paper suggested that certain principles should be abided by in choosing evaluation indices. In addition to such principles as scientificity, simplicity, data accessibility, representativeness, the following ones should also be satisfied:
1. The selected indices must meet basic needs of both humans and lakes watershed eco-systems
According to Maslow Pyramid Theory, to satisfy the requirements of human survival is the foundation of

Please cite this article as: Li R., 2016, An evaluation research into sustainable development of water resources in lakes watershed, Chemical Engineering Transactions, 51, 985-990 DOI:10.3303/CET1651165

ecological and social progress, and to maintain eco-service functions of lakes watershed guarantees SWRDWLB. (Marshall, 2005)

2. The selected indices reflect suitable spatiotemporal scales

In index selection and corresponding standard determination, future needs should be taken into account. At the same time, the action of taking lakes watershed as spatial scales is supposed to conform to migration and transformation concerning water resource hydrology and aquatic environment. (Abu-Zeid, 1998)

3. The selected indices embody SWRDWLB characteristics

SWRDWLB depends on natural attributes of water resources together with mutual effects between water resources and ecological-social systems. Therefore, the established evaluation system is required to embody the aforementioned characteristics of water resources & aquatic environments.

4. The selected indices should combine domestic development tendency with management bottleneck of water resources & aquatic environments

Fairness, high efficiency, and harmony constitute the development theme and direction in China. In this connection, the evaluation index system is supposed to highlight key issues of water resources & aquatic environments management in China.

2.2 The evaluation system of SWRDWLB

In combination with SWRDWLB analysis and scores from experts in the field of water resources, and according to statistic data, the paper constructed an evaluation system of SWRDWLB. The specific evaluation indices and grades are shown in Table 1.

Table 1: Specific evaluation indices and grades of SWRDWLB

	Tier one subsystem	Influential factor	Grade & scale			
			Grade I	Grade II	Grade III	Grade IV
SWRDWLB system	aquatic environments X_1	Water quality X_{11}	oligotrophic	Poorly mesotrophic	mesotrophic	eutrophic
		Water resource volume per capita/m^3 X_{12}	500	1000	1700	3500
		Forest coverage rate X_{13}	≤0.2	0.2~0.35	0.35~0.5	≥0.5
		Water resource development degree X_{14}	≥0.6	0.5~0.6	0.4~0.5	≤0.4
		Underground water exploitation degree X_{15}	≥0.7	0.6~0.7	0.5~0.6	≤0.5
		Domestic water consumption per capita X_{16}	≤50	50~80	80~110	≥110
		Waste water treatment rate X_{17}	≤0.4	0.4~0.6	0.6~0.8	≥0.8
		Soil and water loss area proportion X_{18}	≥0.7	0.5~0.7	0.3~0.5	≤0.3
	Society X_2	Population density /head ·km^{-2} X_{21}	≥800	600~800	200~600	≤200
		Urbanization level X_{22}	≤0.2	0.2~0.35	0.35~0.6	≥0.6
		Fitness level X_{23}	≤0.5	0.5~0.65	0.65~0.8	≥0.8
		Literacy rate X_{24}	≤0.4	0.4~0.6	0.6~0.8	≥0.8
		Water resource harmonization mechanism construction degree X_{25}	≤0.3	0.3~0.6	0.6~0.8	≥0.8
	Economy X_3	GDP per capita /10^{4}yuan·head^{-1} X_{31}	≤0.3	0.3~0.8	0.8~1.2	≥1.2
		Ratio of the service sector's output value X_{32}	≤0.15	0.15~0.2	0.2~0.35	≥0.35
		Water consumption volume for GDP per capita/t·10^4 yuan^{-1} X_{33}	≥400	200~400	100~200	≤100
		water environment improvement investment coefficient X_{34}	≤0.005	0.005~0.015	0.015~0.03	≥0.03
		Water conservation facilities investment coefficient X_{35}	≤0.02	0.02~0.04	0.04~0.06	≥0.06

3. The evaluation model of SWRDWLB

3.1 Evaluation index weight calculation by means of analytic hierarchy process

Analytic hierarchy process was used to calculate evaluation index weights of SWRDWLB, where the index set for criterion layer was $X=(X_1, X_2, X_3, X_4)$, and the index evaluation set was $X_{i=(}X_{i,}\ X_{i2,......)}$=. Both two sets had passed consistency checking (Hang and Li, 2009).

Table 2: Evaluation index weights of SWRDWLB

index	X_1	X_2	X_3	Weight W_i
	0.45	0.32	0.23	
X_{11}	0.156			0.070
X_{12}	0.151			0.068
X_{13}	0.098			0.044
X_{14}	0.132			0.059
X_{15}	0.116			0.052
X_{16}	0.076			0.034
X_{17}	0.124			0.056
X_{18}	0.147			0.066
X_{21}		0.231		0.074
X_{22}		0.105		0.034
X_{23}		0.188		0.060
X_{24}		0.214		0.068
X_{25}		0.262		0.084
X_{31}			0.256	0.059
X_{32}			0.122	0.028
X_{33}			0.152	0.035
X_{34}			0.206	0.047
X_{35}	0.45	0.32	0.23	0.061

3.2 Grey classification determination

According to SWRDWLB levels and expert scores, SWRDWLB could be classified into four grades: Grade I, Grade II, Grade III, and Grade IV. There were k grey classifications for evaluation, and $k=1,2,3,4$. The classification criteria of SWRDWLB grades are shown in Table 3. (Shao Ping, 2003)

Table 3: Classification criteria of SWRDWLB grades

Grade	criteria
Grade I	Lack of water resources, extremely improper underground water exploitation, few water resources per capita, low waste water treatment rate
Grade II	Moderate storage of water resources, improper underground water exploitation, small investment in water resource facilities, and poor-quality waste water treatment
Grade III	Relatively abundant water resources, nutrient-rich, proper underground water exploitation, relatively high forest coverage rate, little soil and water loss
Grade IV	abundant water resources, hypereutrophic, proper underground water exploitation, much investment in water resource facilities, high forest coverage rate

On the foundation of SWRDWLB indices and its requirements, four grey classifications could be established (referring to Table 1).

3.3 Establishment of SWRDWLB whitenization weight function

The grey evaluation method based on endpoint triangular whitenization weight function was used. Specifically,

$$f_i^k(x_i)=\begin{cases} 0, & x_i \notin [a_{k-1}, a_{k+2}] \\ \dfrac{x_i-a_{k-1}}{\lambda_k-a_{k-1}}, & x_i \in [a_{k-1}, \lambda_k] \\ \dfrac{a_{k+2}-x_i}{a_{k+2}-\lambda_k}, & x_i \in [\lambda_k, a_{k+2}] \end{cases} \tag{1}$$

Where x_i denoted the assessment value of Index i, and k represented the evaluation grey classification. Substitute expert scores x_i into equation (1), and obtain the whitenization weight function of $f_i^k(x_i)$, where $\lambda_k=\dfrac{a_k+a_{k+1}}{2}$, $a_0=a_1-5$, and $a_6=a_5+5$.

3.4 calculation of whitenization weight clustering vectors of the evaluation model of SWRDWLB

$\sigma_i^k=\sum_{i=1}^{m} f_i^k(x_i)W_i$ denoted the variable weight grey clustering coefficient for the k grey classification, from which the clustering coefficient set $(\sigma_i^1,\sigma_i^2,\sigma_i^3,\sigma_i^4)$ was obtained. The clustering classification was determined with reference to the principle of MDM (maximum degree of membership), where x_i represented the evaluation value of SWRDWLB indices, $f_i^k(x_i)$ was the whitenization weight function for the k subcategory of Index i, and W_i denoted the weight of Index i in integral clustering classification.

4. Simulation computation of SWRDWLB for the Yellow River Basin

Based on the above established model and requirements for water resource evaluation, and in combination with scores from five experts, the paper summarized grey classification scores of SWRDWLB for the Yellow River Basin in Table 4.

Through calculation from the evaluation model of SWRDWLB, it could be obtained that:

$\sigma^1=0.2132$, $\sigma^2=0.4061$, $\sigma^3=0.4445$, $\sigma^4=0.3256$,

Thus, the clustering possibility of four grey classifications concerning SWRDWLB for the Yellow River Basin was:

$\sigma^3>\sigma^2>\sigma^4>\sigma^1$,

According to the principle of MDM, the evaluation grade of SWRDWLB for the Yellow River Basin was Grade Ⅲ.

Table 4: Grey classification score sheet of SWRDWLB for the Yellow River Basin

index	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average score X_{ij}
X_{11}	20	18	19	21	26	21
X_{12}	56	52	46	54	48	51
X_{13}	8	10	4	9	12	9
X_{14}	16	26	18	19	28	21
X_{15}	72	68	48	64	44	59
X_{16}	21	18	15	23	16	19
X_{17}	14	18	8	12	22	15
X_{18}	18	20	14	17	12	16
X_{21}	30	12	16	21	24	21
X_{22}	18	20	14	17	12	16
X_{23}	13	14	11	18	15	14
X_{24}	28	26	25	24	31	27
X_{25}	8	10	4	9	12	9
X_{31}	20	18	19	21	26	21
X_{32}	56	52	46	54	48	51
X_{33}	8	10	4	9	12	9
X_{34}	16	26	18	19	28	21
X_{35}	21	18	15	23	16	19

5. Conclusion

The paper conducts evaluation research on SWRDWLB, and establishes a grey clustering evaluation model for reasonable assessment. In this way, the evaluation result is more proximate to real values.

Acknowledgements

Project Name: Anhui province colleges and universities outstanding youth talent support program in 2014. Project Number: NO73;

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