Development and Application of the Software for Water Ecological Index Screening

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Abstract—The objective of this article is to apply a program for ecological indicator screening base on a new method, which is the Comprehensive Method for Water Ecological Index Screening (CMWEIS). CMWEIS is based on the Principal Component Analysis (PCA) and Delphi Method (DM, a kind of expert investigation method). Not only the objective factors but also the subjective factors are considered. Using CMWEIS, the ecological indicators were sorted in the range of Liao River basin. 25 ecological indexes, 2 years' observed data of the main stream of Liao River were considered. Ten specialists were invited to answer the designed questionnaires. After 5 times of screening, the score of each ecological index was provided and 11 indexes were selected. CMWEIS considered both the objective characters of the indicators and the subjective adjustment of the specialists. So the indexes selected by WEIDSM could reflect the ecological status well and truly. The model was programmed by Visual Basic 6.0, so that all the statistical calculations were done by the computer. It could be expected that CMWEIS could give the sequence of ecological indicators quickly, so as to make ecological monitoring or evaluating more effectively.

Keywords- ecological index; index screening; principal component analysis; Delphi method

I. INTRODUCTION

Two basic methods are widely used to evaluate a river ecosystem's health status [1]. They are Indicator Species Method (ISM) and Comprehensive Indicator System Method (CISM). The typical ISMs are IBI, RIVPACS, AUSRIVAS, AAI and IPS and so on [2-4]. A typical ISM can only reflect the influence on one certain respect, and different selected species may lead to different results. CISM collects more comprehensive information, and covers the shortage of ISM. The representative CISMs, such as RBPs, SERCON, RCE, and ISC [5, 6] were widely used in recent years. ZHAO Yan-Wei [7] provided a 5-level evaluation criterion, which included five factors: water quantity, water quality, aquatic organism, physical structure and riparian area. River ecosystem is a complex giant system with both objective factors and subjective factors. Objective factors include hydrology, water quality, microorganism conditions etc. Subjective factors include the river's service function, the selection of evaluation criterions and so on [8]. Along with the development of research on the river ecosystem, the CISM include not only the natural properties but also of the social attributes such as population and economical indicators [9]. In summary, firstly, the comprehensive river ecosystem indicator system should include both objective and subjective properties, secondly, a scientific comprehensive screening method considering both objective and subjective factors will be needed to screen the indicators. Based on the previous research results, a river ecosystem index system was established, which had 5 categories, 3 levels and 3 grades. Aiming the objective and subjective properties, the PCA and DM were both used to screen the indicators in the CMWEIS. The shortcomings of PCA and DM were overcome. The CMWEIS was programmed with Visual Basic 6.0 computer language and applied to screen the 25 indicators in main stream of Liao River, the importance of each indicator was scored and sorted.

II. RESEARCH METHOD

Usually, many indicators are included in a river ecosystem. Based on the current research level, it have not been made clear that the relations among the indicators[10]. Therefore, in order to get more reliable information, too many indicators should be observed. More or less, one indicator must have some dependency relationship with another. PCA could calculate the Contribution Rates (CR) through statistic analysis method, so as to use lesser variables instead of original more variables[11-13]. Because of the subjective properties of the river ecosystem, it could not meet the demand to use only PCA. DM is another method to lessen indicators, which takes advantages of the knowledge and experiences of the experts[14]. DM has been widely used as a kind of subjective method. Considering the shortcomings and advantages of these tow method, the CMWEIS was developed to screen the indicators. A river ecological index system should reflect the evolution of the river objectively, fully and quantitatively. Therefore, the primary selected indicators were divided into five categories: hydrology and water quality, social economic, vegetation of riparian areas, biological diversity and meteorology. As shown in Table 1, 25 indicators were selected primarily, and there are 5 indicators from each category. Considering the importance and the economical and technological accessibility of each indicator, the 25 indicators were divided into three levels. (1) Prior Indicator (PI), PI is of great importance and with fairly well economical and technological accessibility. (2) Regular Indicator (RI), RI is of common importance and with economical and technological accessibility. (3) Long-dated Indicator (LI), LI is fairly important but with poor accessibility.

As shown in Fig .1, firstly, the data of the selected 25 indicators were observed or collected in the Data Table (DT). Secondly, with PCA method, Calculated Relative Scores (CRS) of the 25 indicators were calculated and written in the Contribution Rate Table (CRT), as shown in Table 1, column A, B, C and E. Ten experts were invited, and each expert should give the Expert Score (ES) of each index, as shown in Table 1, column D independently. The averages of the scores from the 10 experts' questionnaires were calculated so that the Expert Score Table (EST) came into being. Based on the EST and CRT, through CMWEIS, the Comprehensive Scores (CS) of these 25 indicators and their sequence were obtained. First of all, the weights of expert's score (w) and contribution score should be determined according to (1) and (2). Then the CS of the indicator would be calculated by (3). Then the Sequence Number (SN) should be determined as shown in Table 1, column G.

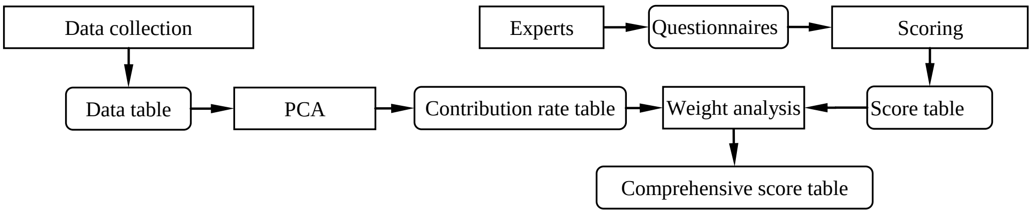

Figure 1. Technology roadmap of the Comprehensive Screening Method

TABLE I. SELECTED INDEXES AND THEIR SCORES

Category	**Indicator Name and Unit**	Level	ES	CRS	CS	SN
A	***B***	***C***	***D***	***E***	***F***	***G***
Hydrology and water quality	Flux/[m^3 s^{-1}]	PI	95	94.0	94.5	2
	Ammonia nitrogen/[mg·L^{-1}]	RI	95	78.8	86.9	6
	BOD5/[mg·L^{-1}]	PI	95	96.6	95.8	1
	Dissolved oxygen/[mg·L^{-1}]	PI	95	85.6	90.3	3
	Water temperature/[℃]	RI	95	69.0	82.0	12
Social economy	Human disturbance degree	PI	95	14.2	54.6	19
	Human activity degree	RI	70	16.4	43.2	21
	Population density/[persons·km^{-2}]	RI	70	84.8	82.4	10
	Industrial add value unit area/[yuan·km^{-2}]	RI	70	36.4	53.2	20
	Agricultural production unit area/[yuan·km^{-2}]	RI	80	30.8	55.4	18
Vegetation cover	Vegetation cover kind	PI	90	59.4	74.7	15
	Grass kind	RI	60	80.8	70.4	16
	Vegetation coverage/[%]	RI	95	69.8	82.4	11
	Willow kind	RI	60	6.2	33.1	25
	Emerging plant kind	PI	95	56.0	75.5	14
Biodiversity	The algae species	PI	80	92.4	86.2	7
	Benthic animal species	PI	95	81.4	88.2	5
	Fish species	PI	95	85.0	90.0	4
	Sediment microbial species	RI	95	76.8	85.9	8
	Population number	RI	95	60.0	77.5	13
Weather	Sunshine duration/[h·a^{-1}]	RI	76	61.0	68.5	17
	Annual precipitation /[mm]	RI	30	90.4	85.2	9
	Radiation intensity/[J·m^{-2}]	RI	55	12.6	33.8	22
	Annual evaporation/[mm]	RI	55	12.2	33.6	23
	Wind velocity/[m s^{-1}]	RI	20	46.4	33.2	24

$$w = \frac{\sum_{i=1}^{25} f(x_i)}{30 \times 25} \times 50\%, \quad f(x) = \begin{cases} 30, x \geq 30 \\ x, x < 30 \end{cases} \tag{1}$$

$$w^* = 1 - w \tag{2}$$

$$S = S_1 \times w + S_2 \times w^* \tag{3}$$

Where, x means the number of an indicator; w is the weight of contribution rate of the indicator, w^* is the weight of expert score of the indicator. S is the comprehensive score of an indicator; S_1 is the score from PCA; S_2 is the score from DM.

At the beginning of every round (except for the first one), the comprehensive results were to be shown to the experts. So each expert could adjust his evaluation properly according to the results from statistical analysis and other specialists. Repeating this kind of works, more scientific and reliable screening results would be worked out. The statistic and calculation work would be done by the computer automatically through programming. The technical route is shown in Fig .2.

The WEIDSM based on PCA and Delphi Method was designed to grading the water ecological indicators, so as to make a comprehensive analysis on both objective and subjective factors. The measured data during ten years (from 2004 to 2014) of Liao He River ecosystem have been collected and brought to the ecological database named "EcoIndex.mdb". There are a datasheet named "Msdata.mdb" which contains the all the measured data in the database. The information about the monitoring sections and hydrological stations etc. was recorded in the datasheet named "StationInfo.mdb" and the names of the water ecosystem indexes were recorded in the datasheet named "IndexName.mdb". There are 20000 records of measured data in the datasheet named "Msdata.mdb". The data records should be added or updated regularly with monitoring experiments and data collection.

At the beginning of each of screening, the current data were used to analyze and calculate with PCAM. All the records in the datasheet (named "Msdata.mdb") were read firstly, the records whose measure item were the same as the "Name" item in Table 1 were selected out. Then, the weights of each selected items were calculated with (1) and (2). Furthermore, the expert questionnaires were delivered to the ten appointed specialists. Then each expert invited should answer for the questionnaire independently.

The screening work should be done round by round. And the experts would be expected to use the former round's information for reference. Five rounds of screening works were done during recent two years (from 2012 to 2014). 50 expert questionnaires were treated. One example expert questionnaire of the second round was listed in the paper. Each invited specialist should write down his scores base on both his own judgment and the referential information.

As the updating of the observed data, each expert could adjust his determination according to last comprehensive scores. In other words, CMWEIS might be only once, and might be more times, more times could give more accuracy results. Column F of Table 1 showed the results of five times of screening based the data observed from 2004 to 2014.

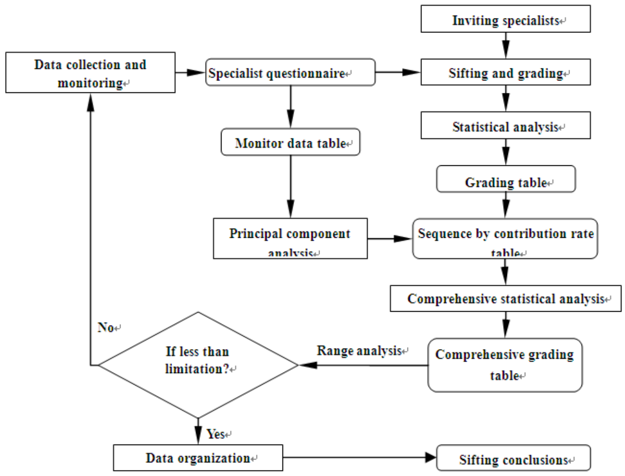

Figure 2. Pie chart of summations by categories

III. RESULTS AND DISCUSSION

As shown in Table 1, 25 indicators were considered as direct or indirect factors which would reflect the health status of the ecosystem of Liao River Basin. The indicators in Table 1 included more than 5 subjects. Long-term monitoring those 25 indicators would cost a lot of people and material recourses. Besides, more data would need more time and labors to statistic and analyze. Therefore, it would be very helpful to raise efficiency that screened those indexes with proper method and let computer do the statistic calculation automatically. CMWEIS was provided and programmed in the paper. The program was written with Visual Basic 6.0, based on the Access Database. It makes the method safer and more effective. All the statistical work was done by the program, a lot of time and labor were saved.

The comprehensive scores were obtained through five times of screening with CMWEIS, as shown in Table 1, column G, where was the Sequence Number (SN). For instance, the comprehensive score of BOD is the highest one, its SN is 1. The indicator with higher score is more important. Considering the comprehensive rule, the indicators should be selected in the five categories, therefore 11 indicators were selected as shown in table 1, the indicators whose sequence numbers are from 1 to 11. In the 11 selected indicators, there are 4 from hydrology and water quality category, 4 from biodiversity category, 1 from vegetation cover category, 1 from social economy category and 1 form weather category.

As shown in Fig .3, the sum of the selected hydrology and water quality indicators' score is 38% of the sum of the selected 11 indicators, and the sum of the selected biodiversity indicators' score is 36% of the sum of the selected 11 indicators. This illustrates that the hydrology and water quality indicators and biodiversity indicators are of great importance and should be taken seriously.

Among the selected 11 indicators, the maximum score is 95.8 and the minimum score is 82.4, the difference of them is 13.4, which means the 11 given indicators are playing similar roles in the river ecosystem. Therefore, in order to evaluate the health of a river ecosystem, a comprehensive consideration of the 11 indicators will be desirable.

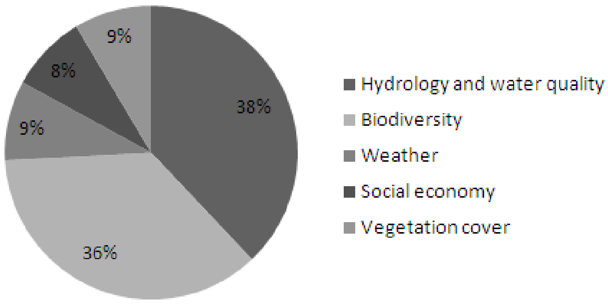

Figure 3. Pie chart of summations by categories

IV. CONCLUSIONS AND PROSPECTS

A comprehensive method for index screening was provided and programmed. The monitoring data from 2004 to 2014 was used to screen the indicators for five times. More than five times also might perform according to the will of managers. By executing the program and updating the data observed or collected, the comprehensive scores and their sequence of the indicators were provided. Therefore, 11 indicators whose scores were higher were selected. The importance of each indicator could be calculated with this method, therefore, we could pay fairly attention to the indicators of more importance, then time and resources could be saved.

In fact, CMWEIS includes a lot of statistical analyses and calculation. It means too much repetitive work that should be done. By using Visual Basic 6.0 computer language, CMWEIS was programmed basing on the database, therefore all the statistical analyses and calculation should be done by the computer. The comprehensiveness was considered, at the same time the workload was decreased.

The weight distribution model was established and the weights of scores by PCA and DM were calculated. PCA could consider the objective factors well, and DM could take all the experts' opinion for into account. So the CMWEIS could consider both objective factors and subjective factors. Therefore, through using of CMWEIS, the shortcomings of PCA and DM were overcome perfectly.

CMWEIS could not only screen the indicators once but also screen for more than once within a short or long period. The screening results with CMWEIS would change with the data updated in the database. The results will different with the times of screen, obviously. From the perspective of development of ecosystem, this method is more scientific that any other method that could only give changeless results.

Based on PCA and DM, a useful and effective program was provided to screen the indicators of an ecosystem. The program could save much time and workload, and consider subjective and objective factors of river ecosystem perfectly. But it is not more than a kind of statistical method, the inner mechanism of the interaction of the indexes is expected for further investigation.

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REFERENCES

[1] YE Min, ZHANG Li, "Preliminary Discussion of the Evaluation Index System For the Aquatic Ecosystem of the Healthy Yangtze River," Resources and Environment in the Yangtze Basin, Vol. 15 , Mar. 2010, pp.72-72

[2] KARR J R, "Assessment of biotic integrity using fish communities," Fisheries, Vol. 6, Dec. 1981, pp.21-26

[3] PETEREN R C, "The RCE: A riparian, channel, and environmental inventory for small streams in the agriculture landscape ," Freshwater Biology, Vol.27, Apr. 2011, pp.295-312

[4] LADSON A R, WHITEL J, DOOLAN J A, "Development and testing of an index of stream condition for waterway management in Australia ," Freshwater Biology, Vol.41, Nov. 2011,p.453-462

[5] AN K G, PARK S S, SHIN J Y, "An evaluation of a river health using the index of biological integrity along with relations to chemical and habitat conditions," Environment International, Vol. 28, Nov. 2012, p.411-416

[6] DAVIS N M, WEAVER V, PARKS K, " An assessment of water quality, physical habitat, and biological integrity of an urban stream in Wichita, Kansas, prior to restoration improvements (phase I)," Archives of Environmental Contamination and Toxicology, Vol. 44, Nov. 2003, p.351-362

[7] ZHAO Yan-wei, YANG Zhi-feng, "Preliminary study on assessment of urban river ecosystem health," Advances in water science, Vol.16, May. 2012, p.350-385

[8] Electronic Publication: Digital Object Identifiers (DOIs):

[9] ZUO Chan, XU Min-de, CHAI Guo-ping, XUE Jia, "Analysis of Ecosystem Health Indicator System," Industrial safety and environmental protection, Vol. 40, Nov. 2014, p.221-233

[10] Cao QIAN-qian, WANG Xing-ke, "Study on the evaluation index system of river ecological restoration," Environmental protection science, Vol.20, Apr. 2014, p.24-37

[11] M. Kock-Schulmeyer, A. Ginebreda, S. Gonzalez, J. L. Cortina, M. L. de Alda, D. Barcelo, "Analysis of the occurrence and risk assessment of polar pesticides in the Llobregat River Basin, Proc. IEEE Symp. Computational Intelligence in Scheduling (SCIS 08), IEEE Press, Nov. 2011, pp. 17-26, doi:11.1206/SCIS.2011.342320.

[12] S.ORFANIDIS, P. PANYOTIDIS, K. I. UGLAND, "Ecological Evaluation Index continuous formula application: a step forward for functional groups, the formula and reference condition values," Mediterranean Marine Science, Vol 12. Dec. 2011, pp.199-231

[13] V. Osorio, R.Marce, S. Gonzlez, J.L. Cortina, M. L. de Alda, D. Barcelo, "Analysis of the occurrence and risk assessment of polar pesticides in the Llobregat River Basin," Chemosphere, Vol. 86, May. 2012, pp.8-16

[14] A. Dadolahi-Sohrab. F. Arjomand. M. Fadaei-Nasab, "Water quality index as a simple indicator of watersheds pollution in southwestern part of Iran," Water Environ. Vod. 26, Mar. 2012, pp.445-454