Application of Grey Clustering Method in Eutrophication Assessment of Wetland

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Abstract: Grey clustering method is applies to evaluate the water eutrophication of wetland, in order to propose a superior evaluation system which is suitable for wetland eutrophication assessment. Eutrophication degree is divided into 6 classifications, and threshold of each classification makes reference to eutrophication standard of Chinese lake and eutrophication characteristics of wetland. Whitenization weight function is used to describe the limit of eutrophication classification, and clustering weight is selected correctly. Finally, based on grey theory, a mathematical model for evaluating water eutrophication of wetland is proposed. The application of this method to evaluate the water eutrophication in Zhalong Wetland is given as an example for demonstration. It proves clustering model proposed is exact, comparable and applied. [The Journal of American Science. 2006;2(4):53-58].

Keywords: grey clustering method; eutrophication of wetland; assessment; clustering weight

Introduction

The water is the key of maintaining wetland ecosystem function, and in the wetland surface water has the following characteristics: water flow is quite slow, water depth is very shallow, and water body is occluded, in addition there is point pollution, surface pollution and water shortage. Under these conditions the water body eutrophication easily happens. Once it enters the eutrophication stage, water body can lose its functions, which causes the succession of wetland from hygrocolization habitat to xerophilization habitat, the bog can be dry, and the wetland finally vanishes. The eutrophication evaluation of water body makes the accurate judgment to nutrition state by a series of indexes related the water body nutrition condition and their relations[1]. At present main eutrophication assessment methods are as fellows: single parameter method, comprehensive exponential method, probability statistics method, thermodynamics analytic method, fuzzy appraisal method[2], gray appraisal method and so on. The wetland nutrition state is influenced and controlled by many kinds of factors, various parameters affects and restricts mutually, so it is necessary to make synthetic eutrophication assessment of many kinds of parameters. Eutrophication monitoring data are obtained in the limited time and spatial scope, the information is not incomplete or inaccurate, namely the partial information is known, the partial information is unknown or is uncertatin, so the water environment system is a gray system[15]. Therefore, this article applies grey clustering method (multi- parameters synthetic assessment) to eutrophication assessment for the wetland water body.

1. Basic principle of grey clustering method

1.1 Basic concepts

The grey system theory has evolved from "grey box" and "black box", namely, color depth shows complete extent of system information. The information system whose internal characteristics is known is white system; Unknown or uncertain information systems is black system; System that contains known, unknown or non-known information is grey system [3]. The grey system theory is a system analysis method, which could make full use of known information to decrease unknown information, finally impersonally and truly reflect the essence of system[4]. Grey system is described by grey number, grey equation, grey matrix etc. Thereinto grey number is basic unit or cell. Grey number is the number whose scope is known, but whose exact value is unknown, and it can be remarked $\otimes$. In the application, grey number is an interval or a general number set[5]. As far as grey number is whitenizated, commonly using whitenization weight function describes close degree of a grey number in the interval of its obtained value.

1.2 General flow of grey clustering assessment model

Supposed that there are n cluster objects, m cluster indexes, s different grey classifications, according to sample value x_{ij} (i=1, 2, …, n; j =1, 2, …, m) of the i th (i=1, 2, …, n) object to j (j=1, 2, …, m) index, the i th object is put into the k th ($k \in \{1, 2, …, s\}$ grey classification, which is called grey cluser[6].There are two grey cluster methods: grey incidence and whitenization weight function cluster. The later is mainly used to check if object observed is attributed to different classifications which are supposed in advance. Therefore, it is the same with eutrophication evaluation of wetland. The general flow of its assessment model is as follows:

(1) give out whitenization value matrix of sample $D = \{x_{ij}\}$.
(2) confirm whitenization weight function marked f_j^k ,where f_j^k is the whitenization weight function of that the j th index is attributed to the k th grey classification
(3) confirm clustering weight η_j^k.
(4) confirm clustering coefficient σ_i^k.
(5) construct clustering vector.
(6) confirm which grey class each cluster object is attributed to.

2. Establishment of mathematical model

2.1Assessment indexes and graduation standard of eutrophication

Indexes of water body eutrophication include generally: total phosphorus（TP）,total nitrogen（TN）,transparence（SD）, chlorophyll a（Chla）, biochemical oxygen demand（BOD_5）, Chemical oxygen demand（COD）, dissolved oxygen（DO）, NH_3-N etc[7].These indexes constitute grey cluster index set

$$U = (TP, TN, SD, Chla, BOD_5, COD, DO, NH_3 - N, \cdots).$$

Though different researchers have different Eutrophication classification standards, the total trend is still accordant. In this study degree of water body eutrophication is divided into 6 classifications, so grey set is $V=$ { oligotrophic（the fist）, lower-mesotrophi（the second）, mesotrophic（the third）, upper-mesotrophic（the fourth）, eutrophic（the fifth）, hypereutorphi（the sixth）}. Standard value of each assessment classification is marked λ_j^k. λ_j^k is confirmed by consulting correspond standard, based on different area studied, different data, and some indexes value is adjusted on basis of water area background and water purpose. λ_j^k could be confirmed by oneself based on water area background.

2.2 Confirming whitenization weight function

Whitenization weight function of the j th pollutant to the k th evaluation classification is marked $f_j^k(x_{ij})$,and f_j^k is such a shape, that f_j^k takes rank standard value as the center point, then fuzzily launches to two sides, left slopes are mutually the inverse, and each apex f_j^k=1.It shows in Figure 1[8].

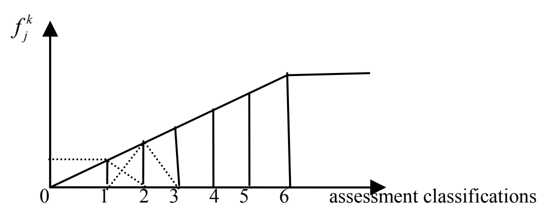

Figure 1. Principle of whitenization weight function

Whitenization weight function of the j th pollutant to the first classification is equation （1）, that of the j th pollutant to the kth classification is equation （2）,and that of the j th pollutant to the sixth classification is equation （3）. SD and DO are different from the other pollutants, because with increase of their value, degree of eutrophication decreases. Therefore, whitenization weight functions are different, which are listed as equation (4)-(6).

$$f_j^1=\begin{cases}1 & x\in\left[0,\lambda_j^1\right]\\ \dfrac{\lambda_j^2-x}{\lambda_j^2-\lambda_j^1} & x\in\left(\lambda_j^1,\lambda_j^2\right)\\ 0 & x\in\left[\lambda_j^2,\infty\right)\end{cases} \quad (1)$$

$$f_j^k=\begin{cases}\dfrac{x-\lambda_j^{k-1}}{\lambda_j^k-\lambda_j^{k-1}} & x\in\left(\lambda_j^{k-1},\lambda_j^k\right]\\ \dfrac{\lambda_j^{k+1}-x}{\lambda_j^{k+1}-\lambda_j^k} & x\in\left(\lambda_j^k,\lambda_j^{k+1}\right)\\ 0 & x\in\left[0,\lambda_j^{k-1}\right]\cup\left[\lambda_j^{k+1},\infty\right)\end{cases} \quad (2)$$

$$f_j^6=\begin{cases}\dfrac{x-\lambda_j^5}{\lambda_j^6-\lambda_j^5} & x\in\left(\lambda_j^5,\lambda_j^6\right)\\ 1 & x\in\left[\lambda_j^6,+\infty\right)\\ 0 & x\in\left[0,\lambda_j^5\right]\end{cases} \quad (3)$$

$$f_j^1=\begin{cases}1 & x\in\left[\lambda_j^1,\infty\right)\\ \dfrac{\lambda_j^2-x}{\lambda_j^2-\lambda_j^1} & x\in\left(\lambda_j^2,\lambda_j^1\right)\\ 0 & x\in\left[0,\lambda_j^2\right]\end{cases} \quad (4)$$

$$f_j^k=\begin{cases}0 & x\in\left[0,\lambda_j^{k+1}\right]\cup\left[\lambda_j^{k-1},\infty\right)\\ \dfrac{x-\lambda_j^{k+1}}{\lambda_j^k-\lambda_j^{k+1}} & x\in\left(\lambda_j^{k+1},\lambda_j^k\right]\\ \dfrac{x-\lambda_j^{k-1}}{\lambda_j^k-\lambda_j^{k-1}} & x\in\left(\lambda_j^k,\lambda^{k-1}{}_j\right)\end{cases} \quad (5)$$

$$f_j^6=\begin{cases}1 & x\in\left[0,\lambda_j^6\right]\\ \dfrac{x-\lambda_j^5}{\lambda_j^6-\lambda_j^5} & x\in\left(\lambda_j^6,\lambda_j^5\right)\\ 0 & x\in\left[\lambda_j^5,\infty\right)\end{cases} \quad (6)$$

2.3 Confirming cluster weight

Methods of Confirming cluster weight are as follows:（1） sample mean square method[9].（2）expert experience method[9]. （3）threshold sample method[9]. （4）simplicity threshold method. Supposed that λ_j^k is the threshold of k subclass of j index, then its cluster weight is:

$$\eta_j^k=\frac{\lambda_j^k}{\sum_{j=1}^{m}\lambda_j^k} \quad (7)$$

or

$$\eta_j^k=\frac{1/\lambda_j^k}{\sum_{j=1}^{m}1/\lambda_j^k} \quad (8)$$

In the practical application, according to different study problem, different method might be chosen. In this study, reciprocal method in the simplicity threshold methods is used. This method shows such a thought, that the threshold of pollution is more bigger, its toxicity is more lower, then its weight is more lower[14].This method guarantees different class of each index has different cluster weight, so it can be avoided that eutrophication classification is divided by a fixed standard.

2.4 confirming cluster coefficient

Supposed that σ_i^k is variable weight clustering coefficient of object i attributed to k grey class, then

$$\sigma_i^k=\sum_{j=1}^{m}f_j^k\left(x_{ij}\right)\cdot\eta_j^k \quad (9)$$

clustering coefficient is calculated by whitenization weight function, and it reflects incidence degree of clustering sample to grey classification.

2.5 Clustering vector and evaluation

Supposed that σ_i is clustering vector,

then $\sigma_i=\left(\sigma_i^1,\ \sigma_i^2,\ \cdots,\ \sigma_i^k\right)$ (10)

According to most subjection principle, confirm which class clustering sample belongs to, then

$$\sigma_i^{k^\bullet}=\max_{1\le k\le s}\left\{\sigma_i^k\right\} \quad (11)$$

So it is said that object i belongs to grey class $k^\bullet$.

3. Case Study

3.1 monitoring data and standard value of each classification

Taking Zhalong wetland (the country nature protection area) as the research background, evaluate swamp water body and lake water body, in order to provide gist for fathering water body eutrophication. Monitoring data of Water quality shows in the Table 2. Chla、TP、TN、COD_{Mn} are chosen as main evaluation indexes, and their standard values are marked λ_j^k, which shows in the Table 1 [10][11][12]

Table 1. Eutrophication classification standard of Zhalong Wetland

Evaluation index	The fist	The second	The third	The fourth	The fifth	The sixth
	Oligo-trophic	Lower-mesotrophic	Meso-trophic	Upper-mesotrophic	Eutrophic	Hypereutorphic
Chla (mg/m^3)	1.0	2.0	4.0	10	65	160
TP (mg/m^3)	2.5	5.0	25	50	200	600
TN (mg/m^3)	30	50	300	500	2000	6000
COD_{Mn} (mg/l)	0.3	0.4	2.0	4.0	10	25

Table 2. Eutrophication monitoring data of Zhalong Wetland

Clustering index (j)	Clustering object (i)					
	1	2	3	4	5	6
	Huluxing	Lianpaozi	Long Lake	Zhalong Lake	Houwangjiazi	Wutai
Chla (mg/m^3)	2.01	1.98	2	13.87	2.14	2.04
TP (mg/l)	0.016	0.016	0.016	0.03	0.195	0.23
TN (mg/l)	1.43	1.6	1.77	1.82	2.5	1.49
COD_{Mn} (mg/l)	12.07	10.67	13.64	11.91	9.23	18.11

3.2 Non-dimension data

In the water body eutrophication assessment, clustering indexes have different significance, the dimension is different, we can not calculate them directly, so we must usually change dimension data into non-dimension data. This article uses the average standard value method, namely various monitoring data and the graduation standard value respectively divide the corresponding the average standard value [13]. Non-dimension class standard values show in the Table 3, and non-dimension monitoring data show in the Table 4.

Table 3. Non-dimension eutrophication classification standard value (λ_j^k) of Zhalong Wetland

Evaluation index	The fist	The second	The third	The fourth	The fifth	The sixth
	oligotrophic	Lower-mesotrophic	Mesotrophic	Upper-mesotrophic	Eutrophic	Hypereutorphic
Chla	0.025	0.050	0.099	0.248	1.612	3.967
TP	0.017	0.034	0.170	0.340	1.360	4.079
TN	0.020	0.034	0.203	0.338	1.351	4.054
COD_{Mn}	0.043	0.058	0.288	0.576	1.439	3.597

Table 4. .Non-dimension eutrophication monitoring data (x_{ij}) of Zhalong Wetland

Clustering index (j)	Clustering object (i)					
	1	2	3	4	5	6
	Huluxing	Lianpaozi	Long Lake	Zhalong Lake	Houwangjiazi	Wutai
Chla	0.050	0.049	0.050	0.344	0.053	0.051
TP	0.109	0.109	0.109	0.204	1.326	1.564
TN	0.966	1.081	1.196	1.230	1.690	1.007
COD_{Mn}	1.737	1.535	1.963	1.714	1.328	2.606

3.3 Confirming clustering weight

Make use of equation (8) to calculate clustering weights. The results of clustering weights of evaluation indexes show in the Table 5.

Table 5. Clustering weights (η_j^k) of evaluation indexes in corresponding grey classification

Evaluation index	The fist oligotrophic	The second Lower-mesotrophic	The third Mesotrophic	The fourth Upper-mesotrophic	The fifth Eutrophic	The sixth Hypereutorphic
Chla	0.232	0.208	0.414	0.364	0.222	0.247
TP	0.342	0.306	0.241	0.252	0.263	0.240
TN	0.291	0.306	0.202	0.254	0.265	0.241
COD_{Mn}	0.135	0.179	0.142	0.149	0.249	0.272

3.4 confirming clustering coefficient

The data in the table 3 and table 4 are separately substituted into equation (1) - (3), and then we can obtain incidence degree values of clustering samples to every grey class. The data in the table 5 and incidence degree values obtained are substituted into equation (9), then we can obtain clustering coefficient matrix, which shows (12).

$$\sigma_i^k = \begin{bmatrix} 0.000 & 0.345 & 0.135 & 0.096 & 0.379 & 0.038 \\ 0.005 & 0.342 & 0.133 & 0.068 & 0.432 & 0.012 \\ 0.000 & 0.350 & 0.133 & 0.039 & 0.413 & 0.066 \\ 0.000 & 0.000 & 0.193 & 0.402 & 0.466 & 0.035 \\ 0.000 & 0.192 & 0.029 & 0.028 & 0.704 & 0.030 \\ 0.000 & 0.205 & 0.008 & 0.086 & 0.553 & 0.165 \end{bmatrix} \qquad (12)$$

According to most subjection principle of equation (11), Huluxing, Liaopaozi, Long lake, Zhalong lake, Houwujiazi and Wutai are the fifth which belong to the eutrophic. Though the assessment results of six objects evaluated are all the fifth (the eutrophic), various observation points eutrophication degree orders for Huluxing, Liaopaozi, Long lake, Zhalong lake, Houwujiazi and Wutai because of $\sigma_5^5 > \sigma_6^5 > \sigma_4^5 > \sigma_2^5 > \sigma_3^5 > \sigma_1^5$.

Zhalong wetland directly or indirectly admits the industry and agriculture sewage for a long time. With the development of economy, output of sewage grows day by day. The main pollutant is COD, BOD_5, TN and TP. Large amount of contamination is beyond filter function of wetland to pollutants. Furthermore, the filter function has obviously descended because wetland has been destroyed. From actual investigation condition, eutrophication degree of the most of lakes and the marsh water body is very serious. Therefore, evaluation results accord with actual investigation condition.

4. Conclusion

Grey clustering method (a synthesizing evaluation method) is applied into eutrophication assessment of wetland water body, which could better embody grey characteristic of eutrophication degree. We can synthetically consider all kinds of factors by Grey clustering method. Though calculation method is complicated, we can calculate them by VB program and the other program existed, which can reduce workload. These programs have offered convenience for handling and analyzing a great number of water quality samples.

Choice of weight is simple and objective. Fuzzy mathematics is, too, a synthesizing evaluation method, and its weight selection is identical, namely, each index to different levels has only a weight. As far as grey clustering method is concerned, each index to different levels has different weight. Different weight can avoid irrationality of dividing eutrophication class by fixed standard, so its different weight is more accurate.

Besides, the same class is comparable in the evaluation of grey clustering method.

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