Application of Fuzzy-hierarchal Integrated Evaluation Method on the Oasis Ecosystem Stability

Jinping Zhang [1], Bingtuo Guo [2], Zhichao Yan [3]

1. Department of Water Resources of China Institute of Water Resources & Hydropower Research, Beijing 100044, China, jinping2000_zh@163.com
2. Yellow River Engineering Consulting Co., Ltd., Zhengzhou, Henan Province 450003, China
3. Beijing Shijingshan District Sanitation Administration Center, Beijing 100043, China

Abstract: The factors influenced on the oasis ecosystem stability involve many aspects and the relationships among factors have the characteristic of uncertain and hierarchal. This paper takes the irrigation area of the north of Ningxia (that draws water from the Yellow River) as an example to compare the oasis ecosystem stability of ten calculated units with the method of fuzzy-hierarchal integrated evaluation. The results show that this method is scientific and rational, and is also an effective method to evaluate the oasis ecosystem stability. [The Journal of American Science. 2006;2(3):41-47].

Keywords: fuzzy; hierarchal; oasis; ecosystem; stability

1. Introduction

The oasis ecosystem stability refers to the situation in which the energy flow, material flow, human flow and information flow of the oasis ecosystem can be kept in a good cycle, the existing surroundings of lives in oasis are optimized continuously, and the functions of oasis can also be kept to develop sustainable. Because the basic character of stability is to promote the sustainable development and sustain a good cycle of system, the essence connotation of oasis stability is the sustainable development of oasis ecosystem. [1] From the definition of the oasis ecosystem stability, we can know that the factors influenced on the oasis ecosystem stability involve many aspects and these factors have the characteristics of dynamic and continuous because of they will change themselves in difference time and space.

The oasis is a place with centralized human activities and high developed productivity. The primordial oasis is the long evolutive result of nature, and various species, resources depends on each other on a harmonious state. But this primordial nature balance is broke down by the modern human beings. Because of the limitations of knowledge and technologies, some irrational development and utilization of resources in oasis are appeared, especially water resources, which plays a key role on the subsistence and development of oasis. As a result, the ecosystem of oasis begins to degrade gradually, and further to effect on the prosperity and sustainable development of oasis. Therefore, it is urgent to study the crucial factors that influence on the stability of oasis ecosystem from the view of nature and human, then to make out the corresponding evaluation standard to direct the human activities and make sure the healthy stability and sustainable development of oasis ecosystem.

2. The Establishment of Evaluation Indexes

Because the involved features of oasis ecosystem stability are very complex, the evaluation index system must follow the principles of science, hierarchy, integrated and predication.

Water, land, biology and environment are the four main basic feathers to form the oasis system. Moreover, they are the key feathers who have an important effect on the sustainable development of the oasis ecosystem stability. The human activities are all related to these four feathers and the changes of these feathers are also the reflections and results of human intervention. Therefore, we can make them as the first control indexes of the oasis ecosystem stability evaluation, then to classify them further according to their importance degree. The indexes system is shown in Figure 1.

3. Fuzzy-hierarchal integrated evaluation model

From the evaluation indexes system of oasis ecosystem stability, we can know that the system can be decomposed, so it has the characteristic of hiberarchy. The indexes are related and depended on each other and the relationships among them have uncertain and fuzzy characteristics. This paper evaluates the oasis ecosystem stability by establishing the fuzzy-hierarchal integrated evaluation model. The following is the process of the whole evaluation:

(1) Construct judge matrix $\lfloor u_{ij} \rfloor_{k\times k}$ of each level according to the importance degree $f_{uj}(ui)$ of each index. Table 1 is the judge value of the importance degree of each index.

- The oasis system
  - Water resources
    - Water resources per unit area in farmland (+)
    - Water resources per unit area in non-farmland (+)
    - The water shortage rate in agriculture (-)
    - The water shortage rate in ecosystem, (-)
  - Land resources
    - Plantation index (-)
    - Plantation salinization index (-)
    - Wasteland index (-)
  - Biology resources
    - Woodland index (+)
    - Woodland cover degree (+)
    - Grassland index (+)
    - Grassland cover degree (+)
    - Wetland index (+)
    - Grassland cover rate of ecosystem green equivalent (+)
  - Environment resources
    - Water pollution situation (-)
    - Underground water level depth (effects on salinization +)
    - Underground water level depth (effects on non-salinization -)

Figure 1. Evaluation indexes system of oasis ecosystem stability

Notes: “+” means the positive index and “ –” means the negative index

Table 1. The judge value of the importance degree of index

u_{ij}	1	3	5	7	9	2、4、6、8
$f_{uj}(ui)$	equal important	a little more important	obvious important	strong important	absolute important	between each important degree

(2) Compute the largest eigenvalue $\lambda_{\max}$ and eigenvector ξ of each judge matrix, and to check up the consistent of matrix $\lfloor u_{ij} \rfloor_{k\times k}$.

(3) If the matrix is consistent, we can calculate the fuzzy weight vector $\underset{\sim}{A}$ of each index in the lowest level.

(4) Ascertain the fuzzy matrix of scheme level[2]

Suppose the decision scope V is a collection of schemes (oasis stability evaluation region).

V ={region 1，region 2，…，region m}= $\{v_1, v_2, ..., v_m\}$

The indexes collection which has an important effect on the oasis ecosystem stability is that:

$u = \{f_1，f_2，…，f_n\}$

So, the index vector of each region is as follows:

$v_j = (f_{1j}，f_{2j}，…，f_{nj})^T$， $j = 1，2，\cdots，n$

If the value of index i in the scheme j is considered as f_{ij}, we can get the index value matrix F with m regions and n indexes:

$$F = \begin{pmatrix} f_{11} & f_{12} & \cdots & f_{1m} \\ f_{21} & f_{22} & \cdots & f_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ f_{n1} & f_{n2} & \cdots & f_{nm} \end{pmatrix}$$

When the index f_{ij} can be calculated, the r_{ij} is calculated as:

$$r_{ij} = \begin{cases} 0.1 + \dfrac{f_{i\max} - f_{ij}}{d}, & \text{when } f_{ij} \text{ is a negative index} \\ 0.1 + \dfrac{f_{ij} - f_{i\min}}{d}, & \text{when } f_{ij} \text{ is a positive index} \end{cases}$$

In which, d is the grade difference value and can be calculated as $d = \dfrac{f_{i\max} - f_{i\min}}{1 - 0.1}$, r_{ij} is the evaluation value of the index i in the region j

An evaluation fuzzy matrix is formed by n evaluation values of m regions.

$$\underset{\sim}{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

(5) The integrated fuzzy integrated evaluation results can be got by weighted average model $M(\bullet, +)$:

$$\underset{\sim}{A} \circ \underset{\sim}{R} = \underset{\sim}{C} = (c_1, \ c_2, \ldots c_m)$$

4. Model application

The irrigation area of drawing water from the Yellow River in Ningxia is located in the northwest of China with few rain and strong evaporation, and its ecosystem is very fragility. For recent years, the contradiction between water supply and demand is becoming more serious, and the human activities are more frequent and strong which result in the degradation of oasis ecosystem stability. Therefore, it is necessary to apply the model into this region so as to sustain the harmonious development of oasis soc-economy and eco-environment.

In the model application, the irrigation area is divided into ten calculated units according to the administrative districts. Under the condition of 50 percent of inflow frequent of the Yellow River in 2000, the ecosystem stability of ten units is evaluated and compared.

4.1 Compute fuzzy weight vector $\underset{\sim}{A}$

Aiming at the actual situation of irrigation area, the important degree among indexes is compared to construct a judge matrix. With the software of Matlab, the eigenvalue and eigenvector of corresponding matrix are calculated, and then the matrix's consistence is checked up. At last, the fuzzy weight vector $\underset{\sim}{A}$ is got as:

$$\underset{\sim}{A} = (0.116, 0.088, 0.116, 0.17, 0.075, 0.013, 0.027, 0.036, 0.036, 0.023, 0.023, 0.057, 0.057, 0.097, 0.041, 0.026)$$

4.2 Construct the fuzzy matrix of scheme level

The index values of each single unit in irrigation area are as Table 2 and Table 3 [3]-[5]:

Table 2. The index value of each calculated unit in irrigation under the condition of 50 percent of inflow frequent of the Yellow River in 2000

Unit	Water resources per unit area in farmland (m^3/mu)	Water resources per unit area in non-farmland (m^3/mu)	Water pollution (t/a)	Plantation index	Plantation salinization index	Woodland index	Woodland cover degree	Wetland index
Zhongwei City	671.85	231.23	8817.68	0.31	0.14	0.04	0.34	0.11
Zhongning County	643.80	324.02	5338.07	0.39	0.08	0.03	0.32	0.21
Qintongxia City	604.29	228.32	5224.65	0.41	0.08	0.02	0.31	0.22
Yongxing County	604.26	235.11	5751.90	0.47	0.09	0.02	0.28	0.07
Yinchuan City	568.18	263.09	6678.23	0.51	0.13	0.03	0.32	0.09
Helan County	610.53	294.04	4493.50	0.58	0.17	0.00	0.35	0.06
Pingluo County	579.54	255.15	8297.57	0.47	0.17	0.03	0.31	0.16
Shizuishan City	570.38	180.56	4546.30	0.40	0.22	0.02	0.35	0.12
Wuzhong City	651.10	185.33	7572.40	0.41	0.22	0.04	0.32	0.12
Lingwu City	664.94	277.13	10129.90	0.47	0.18	0.03	0.34	0.15

Table 3. The index value of each calculated unit in irrigation under the condition of 50 percent of inflow frequent of the Yellow River in 2000

unit	Grassland cover degree	Wetland index	Wasteland index	Grassland cover rate of ecosystem green equivalent	The water shortage rate in agriculture	The water shortage rate in ecosystem	Underground water level depth (m)	Underground water level depth (m)
Zhongwei City	0.30	0.01	0.43	0.58	0.00	0.00	2.32	2.32
Zhongning County	0.26	0.01	0.23	0.56	0.00	0.00	1.88	1.88
Qintongxia City	0.29	0.01	0.24	0.54	0.00	0.00	1.70	1.70
Yongxing County	0.43	0.03	0.34	0.60	0.00	0.00	1.61	1.61
Yinchuan City	0.47	0.04	0.20	0.69	0.00	0.00	1.57	1.57
Helan County	0.42	0.08	0.20	0.67	0.00	0.00	1.32	1.32
Pingluo County	0.30	0.03	0.21	0.57	0.00	0.00	1.13	1.13
Shizuishan City	0.48	0.03	0.31	0.64	0.00	0.00	1.46	1.46
Wuzhong City	0.45	0.01	0.30	0.63	0.00	0.00	2.19	2.19
Lingwu City	0.33	0.01	0.23	0.60	0.00	0.00	2.03	2.03

The fuzzy matrix $\underset{\sim}{R}$ is got with the method of the fuzzy matrix of scheme level calculation.

4.3 Fuzzy integrated evaluation

By the above formulation:

$\underset{\sim}{A} \circ \underset{\sim}{R} = \underset{\sim}{C} = (c_1, c_2, \ldots c_m) = (0.106, 0.12, 0.09, 0.09, 0.10, 0.124, 0.079, 0.092, 0.098, 0.101)$ So, the priority order of oasis ecosystem stability of ten calculated units in irrigation area is: Helan County > Zhongning County > Zhongwei City > Lingwu City > Yinchuan City > Wuzhong City > Shizuishan City > Yongning County > Qingtong City > Pingluo County.

5. Oasis ecosystem stability evaluation in each calculated unit

With the method of fuzzy integrated evaluation, we can compare the oasis ecosystem stability of each unit in irrigation area of Ningxia. However, the ecosystem stability of each unit is still not be ensured, so it is need to introduce the corresponding transformation function to transform the evaluation value of each calculated unit, and compare it with the integrated evaluation standard of oasis ecosystem stability. On these results, the oasis ecosystem stability of each unit in irrigation area can be determined.

The integrated evaluation standard of oasis ecosystem stability is as Table 4[6]-[7].

In the process of model calculation, all experts are think the ecosystem stability of Ningxia is in a good situation in 2000. So the index transformation function can be constructed as: $y = -0.245 + 15.61x - 66x^2$. Combing with the fuzzy integrated evaluation results, the oasis ecosystem stability of each unit in irrigation area can be determined as Table 5.

Table 4. The integrated evaluation standard of oasis ecosystem stability

The oasis ecosystem stability	**The integrated evaluation standard**
Best	>=0. 8
Better	0. 6～0. 8
Mediocre	0. 4～0. 6
Worse	0. 2～0. 4
Worst	<0. 2

Table 5. The oasis ecosystem stability of each unit in irrigation area of Ningxia

Unit	Zhongwei City	Zhongning City	Qingtongxia City	Yongning County	Yinchuan City	Helan City	Pingluo County	Shizuishan City	Wuzhong City	Lingwu City
Integrated evaluation value	0.668	0.678	0.624	0.625	0.655	0.676	0.578	0.633	0.652	0.658
Stability situation	Better	Better	Better	Better	Better	Better	Mediocre	Better	Better	Better

From the results, we know that in 2000, when the inflow frequent of the Yellow River is 50 percent, expect Pingluo County, the ecosystem stability of other Counties or Cites in Ningxia irrigation are all better, but are all at the lower limit of good state.

6. Conclusions

The oasis ecosystem stability is a complex problem involving various feathers of various aspects and the stability presents difference changes along with the difference of time and space. With the method of fuzzy-hierarchal integrated evaluation, this paper discusses the oasis ecosystem stability and gets the scientific and rational results, so this method can be adopted and popularized. In modern days, human activities have become the dominant factor to determine whether or not the development of the oasis ecosystem stability is healthy. Therefore, the future study on the oasis ecosystem stability shall be paid more attention to the human activities and their effects on the oasis stability.

Acknowledgement:

Our research is kindly supported by the Key projects of West of China in Ministry of Science and Technology—"Study on Rational Water Resources Allocation of Economy and Ecosystem in Ningxia"（Number: 2004BA901A17）.

Correspondence to:

Jinping Zhang
Room 513 of Department of Water Resources of China Institute of Water Resources & Hydropower Research
20 Chegongzhuang，West Road
Beijing 100044, China
Email: jinping2000_zh@163.com

Received: May 24, 2006.

References

[1] Deling Han. Discuss on the Oasis Stability[J]. Journal of Ningxia University. 1999:6.

[2] Jijian Xie, Chengping Liu. The Method and Application of Fuzzy Math. Wuhan: Science and Engineering Publishing Company in Center China. 2002:5.

[3] Yuansheng Pei, jianhua Wang, Luo Lin. Analysis of effect of South-to-North Water Transfer Project on Aquatic Ecosystems of Haihe River Basin[J]. Acta Ecologica Sinica 2004;24(10):2115-2123.

[4] Jinping Zhang, Zhangjing, Suyan Sun. Application of Grey Correlation Analysis in Oasis Ecosystem Stability Evaluation[J]. Resources Science 2006;28(4):196-198.

[5] Yuansheng Pei, Suyan Sun Chuiyu Lu. Study on Oasis Ecosystem Stability Prediction[J]. Journal of Hydraulic Engineering 2006; 38(4):23-25.

[6] Shishen Yang g. Study on the model of grade division of natural disaster and comparison of disastrous conditions[J]. Journal of Natural Disasters 1997;6(1):9-12.

[7] Yaning Chen, Siquan Yang. The application and model of grey association for evaluation of natural disaster[J].Progress in Geography 1999; 18(2).158-162.