Evaluation on sustainable utilization of water resources in Nansi Lake Basin

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Abstract. Based on the influencing factors of sustainable development by Bossel, the evaluation index system of sustainable utilization of water resources was constructed, which includes 18 indexes considering the development and utilization of water resources, social economy and ecological environment. The evaluation grade was classified into five levels: special, strong, intermediate, light and tiny. Because there were many fuzzy characteristics in this evaluation, this study was constructed an evaluation method of sustainable utilization of water resources based on the variable fuzzy sets model. Taking the Nansi Lake Basin in China as an example, the evaluation method was introduced in detail. The example showed that the evaluation index system constructed in this paper was reasonable and generalized, and the evaluation method was easy to understand, easy to operate and high credibly of the results. In addition, the evaluation results had a certain guiding significance for the sustainable development of water resources.

1. Introduction

With the increase of population and the development of social economy, many water resources problems have arisen, such as shortage of water resources, serious pollution of water environment and degradation of water ecology, which have become the focus of global attention. As water resources is one of the basic supporting conditions for sustainable development, the basic requirement of sustainable development is to ensure the sustainable utilization of water resources. At present, the research on sustainable utilization of water resources is mainly focused on its evaluation indexes and evaluation methods.

A reasonable evaluation indexes can ensure the credibility of evaluation results. At present, indexes of sustainable utilization of water resources mainly included: ① according to the regional scale, it could be divided into national index, regional index and river basin index [1]; ② according to the compound system, it could be divided into natural ecological index, economic index and social index[2]. ③according to the characteristics of water resources system, it could be divided into water resources availability index, water resources utilization degree index and management level index,
water resources comprehensive benefit index; ④ according to the sustainable point of view, it could be divided into extension index, internal index, descriptive index and evaluation index[3]; ⑤ according to epistemological and methodological analysis, it could be divided into economic method index, ecological method index and statistical index[4]; ⑥ according to the range of the evaluation index, it could be divided into single index, thematic index and systematic index[5]. The evaluation methods of sustainable utilization of water resources mainly included qualitative analysis method, systematic evaluation method[6], comprehensive evaluation method[7], coordination degree method, fuzzy comprehensive evaluation method[8], grey clustering evaluation method[9] and so on.

At present, the main problems in the evaluation of sustainable utilization of water resources are as follows: (1) because there are many factors affecting the sustainable utilization of water resources, and there are connections among them, indexes constructed are difficult to include all the influencing factors. Therefore, most scholars constructed evaluation indexes which were suitable for the specific regions; (2) the concepts and evaluation criteria of indexes are not unified, and there are great differences among different researches. In order to solve the above problems, this paper proposed that (1) based on the sustainable development theory put forward by Bossel, the evaluation index system of sustainable utilization of watershed water resources is constructed considering water resources system, socio-economic system and ecological environment system. At the same time, the evaluation criteria of each evaluation index are established according to the characteristics of arid and semi-arid areas in northern China; (2) the evaluation model of sustainable utilization of watershed water resources is developed by variable fuzzy recognition model, and the ways to improve the sustainable utilization grade can be analyzed through the evaluation results.

2. Construction of evaluation index system

2.1. Evaluation index system

According to the influencing factors of sustainable development by Bossel [10], the influencing factors of sustainable utilization of water resources could be summarized as the limit water demand, limited water resources, water resources carrying capacity, water environmental capacity, social system and economic development, ethical value, water resources engineering management system and science and technology. The above eight influencing factors are related to water resources system, socio-economic system and environmental system, which interact and restrict each other. The sustainable development of water resources takes the sustainable development of economy as the premise, the sustainable development of society as the goal, and the sustainable utilization of ecological environment and water resources as the basis. Therefore, the evaluation index system should be constructed from the interaction between the above three systems. In this paper, the evaluation index system is divided into four layers: target layer, criterion layer, constraint layer and index layer. The target layer is reflected by the criterion layer, the criterion layer is described by the constraint layer, and the constraint layer is reflected by the index layer. The target layer is "sustainable utilization grade of water resources", which reflects the coordination degree between the development level of water resources system and economy, society and environment. The criterion layer includes "development and utilization of water resources", "social economy" and "ecological environment", which fully takes into account the impact of water resources, social economy and ecological environment on the sustainable utilization of water resources. The evaluation index system is shown in Table 1.

2.2. Classification of sustainable utilization of water resources

In this paper, the sustainable utilization level of water resources is classified into five grades: special(Grade I), strong(Grade II), intermediate(Grade III), light(Grade IV) and tiny(Grade V). "Special" shows that there is still great potential for the development and utilization of water resources; "tiny" indicates that the development and utilization of water resources is close to the limit, and it is necessary to find new water sources or further improve water use efficiency and strengthen water
saving; other grades belong to the intermediate state. At present, there is no recognized criteria for sustainable utilization of water resources. According to the characteristics of arid and semi-arid areas in northern China, combined with the researches of previous scholars, the evaluation criteria of sustainable utilization of water resources are listed in Table 1.

**Table 1. Evaluation indexes and their criteria.**

| Target layer | Criterion layer | Constraint layer | Index layer | I | II | III | IV | V |
|--------------|-----------------|------------------|-------------|---|----|-----|----|----|
| Development and utilization of water resources | Water resources development indexes | Water production coefficient | ≥0.55 [0.4,0.55] ) | | | | | |
| | | Per capita water resources(m³/person) | ≥3000 [1700,30 00] | | | | | |
| | | Water supply modulus (10,000m³/km²) | ≥30 [15,30] | | | | | |
| | Water resources utilization indexes | Development and utilization rate of water resources(%) | <20 [20,40] | | | | | |
| | | Reuse rate of industrial water (%) | >90 [70,90] | | | | | |
| | | Effective utilization coefficient of agricultural irrigation water | ≥0.8 [0.7,0.8] | | | | | |
| | | Per capita daily domestic water consumption(L· (person ·d)) | <120 [120,150] | | | | | |
| Sustainable utilization of water resources | Social indexes | Population density(person/km²) | <200 [200,500] | | | | | |
| | | Natural population growth rate(‰) | <0.5 [0.5,5] | | | | | |
| | | Urbanization level(%) | >80 [60,80] | | | | | |
| | Economic indexes | Per capita GDP(10,000 RMB/person) | ≥5 [3,5] | | | | | |
| | | Proportion of tertiary industry output value to GDP(%) | ≥60 [50,60] | | | | | |
| | | Proportion of agricultural water use(%) | ≤55 [55,65] | | | | | |
| | | Water consumption of 10,000 RMB industrial added value(m³/10,000 RMB) | ≤20 [20,50] | | | | | |
| | Ecological environment | Proportion of ecological environment water use (%) | ≥5 [3,5] | | | | | |
| | | Rate of surface water quality reaching the standard(%) | ≥80 [70,80] | | | | | |
| | | Urban sewage treatment rate(%) | ≥90 [70,90] | | | | | |
| | | Reuse rate of sewage treatment (%) | ≥80 [60,80] | | | | | |
3. Methods

3.1. Variable fuzzy sets (VFS) and its model[11]
In defining the concept, let us suppose that $U$ is a fuzzy concept (alternative or phenomenon) $A$, and to any elements $u (u \in U)$, $\mu_A (u)$ and $\mu_S (u)$ are relative membership degree (RMD) function that express degrees of attractability and repellency, respectively. Let

$$
D_\delta (u) = \mu_A (u) - \mu_S (u)
$$

where $D_\delta (u)$ is defined as relative difference degree of $u$ to $A$. Mapping

$$
D_\delta : D \rightarrow [-1,1]$$

$$
u \mapsto D_\delta \in [-1,1]
$$
is defined as relative difference function of $u$ to $A$. And we have

$$
\mu_A (u) + \mu_S (u) = 1
$$

Then

$$
\mu_A (u) = \left[1 + D_\delta (u)\right]/2
$$

where $0 \leq \mu_A (u) \leq 1, 0 \leq \mu_S (u) \leq 1.$

We suppose that $X_0=[a,b]$ are attracting (as priority) sets of VFS $V$ on real axis, i.e. interval of $\mu_A (u) > \mu_S (u), X=[c,d]$ is a certain interval containing $X_0$, i.e. $X_0 \subset X.$ According to definition of VFS we know that interval $[c, a]$ and $[b, d]$ all are repelling (as priority) sets of VFS, i.e. interval of $\mu_A (u) < \mu_S (u).$ Suppose that $M$ is point value of $\mu_A (u)=1$ in attracting (as priority) sets $[a, b]$, and $M$ can be determined by actual problem or selected as midpoint value of interval $[a, b]$. $x$ is value of random point in interval $X$, then if $x$ locates at left side of $M$, its difference function is

$$
D_\delta (u) = \begin{cases} 
\frac{x-a}{M-a}^\beta, & x \in [a,M] \\
-\frac{x-a}{b-c}^\beta, & x \in [c,a] 
\end{cases}
$$

And if $x$ locates at right side of $M$, its difference function is

$$
D_\delta (u) = \begin{cases} 
\frac{x-b}{M-b}^\beta, & x \in [M,b] \\
\frac{x-b}{a-b}^\beta, & x \in [b,d] 
\end{cases}
$$

where $\beta$ is an index that higher than 0, usually we take it as $\beta = 1$, viz. Eqs. (5) and (6) become linear functions. Eqs. (5) and (6) satisfy: (i) $x=a, x=b, \mu_A (u) = \mu_S (u) = 0.5$; (ii) $x=M, \mu_A (u) = 1$; (iii) $x=c, x=d, \mu_A (u) = 0$. Then according to Eqs. (5) (or Eqs.(6)) and (4) we can obtain values of relative membership function $\mu_A (u)$ of disquisitive indexes. Then, the integrated relative membership degree can be calculated by Eq. (7).
The average annual amount of water resources in Nansi Lake basin is 6.074 billion m$^3$, and the per capita water resources is less than 300m$^3$, which belongs to a serious water shortage area. Therefore, the evaluation on sustainable utilization of water resources in Nansi Lake basin can not only recognize the current situation and evolution law of sustainable utilization of water resources, but also explore the reasons affecting the sustainable utilization of water resources.

By consulting the statistical yearbooks and water resources bulletins of various cities in Nansi Lake basin, the indexes data from 2010 to 2017 are collected, as shown in Table 2. At the same time, the multi-year average values of indexes and their grades are shown in Table 2.
Table 2. Indexes data from 2010 to 2017.

| Indexes data                                      | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | Average | Grade |
|---------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|---------|-------|
| Water production coefficient                      | 0.077 | 0.081 | 0.076 | 0.069 | 0.076 | 0.079 | 0.099 | 0.104 | 0.083   | V     |
| Per capita water resources                        | 275.4 | 300.0 | 155.0 | 187.1 | 170.4 | 191.0 | 250.5 | 271.2 | 225.1   | V     |
| Water supply modulus                              | 19.5  | 19.7  | 19.0  | 19.0  | 18.2  | 18.4  | 18.5  | 17.0  | 18.7    | II    |
| Development and utilization rate of water resources| 56.2  | 45.0  | 86.1  | 61.6  | 76.7  | 65.4  | 44.1  | 35.2  | 58.8    | III   |
| Reuse rate of industrial water                    | 82.3  | 84.4  | 85.1  | 85.1  | 85.6  | 85.3  | 85.0  | 84.8  | 84.8    | II    |
| Effective utilization coefficient of agricultural irrigation water | 0.569 | 0.585 | 0.601 | 0.617 | 0.625 | 0.632 | 0.638 | 0.645 | 0.614   | III   |
| Per capita daily domestic water consumption       | 72.1  | 73.3  | 72.1  | 72.4  | 73.0  | 72.1  | 72.3  | 70.5  | 72.2    | I     |
| Population density                                | 723.8 | 714.0 | 720.6 | 723.9 | 728.9 | 735.0 | 742.9 | 749.0 | 729.7   | III   |
| Natural population growth rate                    | 1.128 | 0.59  | 0.65  | 0.737 | 2.128 | 0.928 | 1.152 | 0.935 | 1.031   | II    |
| Urbanization level                                | 37.8  | 39.4  | 41.0  | 43.1  | 44.4  | 47.4  | 49.6  | 51.5  | 44.3    | III   |
| Per capita GDP                                    | 2.52  | 2.87  | 3.25  | 3.59  | 3.87  | 4.07  | 4.29  | 4.62  | 3.64    | IV    |
| Proportion of tertiary industry output value to GDP| 36.9  | 38.5  | 40.2  | 41.7  | 43.7  | 45.2  | 46.7  | 46.8  | 42.5    | III   |
| Proportion of agricultural water use              | 79.4  | 77.9  | 77.1  | 77.9  | 77.1  | 76.9  | 76.3  | 74.0  | 77.1    | IV    |
| Water consumption of 10,000 RMB                   | 20.62 | 19.92 | 14.66 | 13.77 | 13.34 | 13.32 | 13.11 | 12.19 | 15.12   | I     |
| Industrial added value                            | 1.31  | 1.24  | 1.78  | 1.77  | 1.52  | 1.68  | 2.02  | 2.57  | 1.74    | VI    |
| Proportion of ecological environment water use    | 42.9  | 48.2  | 53.8  | 61.1  | 66.2  | 70    | 78.6  | 87.5  | 63.5    | III   |
| Rate of surface water quality reaching the standard| 82.3  | 89.5  | 91.4  | 94.1  | 95.4  | 95.7  | 95.6  | 96.7  | 92.6    | I     |
| Urban sewage treatment rate                       | 14.2  | 43.7  | 36.3  | 39.7  | 49.5  | 51.2  | 47.9  | 47.7  | 41.3    | III   |

4.2. Results
Firstly, the interval matrix $I_{ab}$ bound matrix $I_{cd}$ and point value matrix $M$ are calculated as follows.
Secondly, the weights of indexes are determined according to the entropy weight method, $w=(0.081, 0.077, 0.040, 0.054, 0.033, 0.050, 0.069, 0.052, 0.034, 0.069, 0.056, 0.060, 0.053, 0.055, 0.081, 0.066, 0.036, 0.034)$. Thirdly, according to Eq.(11), the integrated relative membership degree is calculated as follows. Finally, according to Eq.(12), the grade characteristic values and grades are calculated by taking $p=1, \alpha=1$, as shown in Table 3.

$$
I_{ab} = \begin{bmatrix}
[1.0, 0.55] & [0.55, 0.4] & [0.4, 0.2] & [0.2, 0.1] & [0.1, 0]
\end{bmatrix}
$$

$$
I_{cd} = \begin{bmatrix}
[3100, 3000] & [3000, 1700] & [1700, 1000] & [1000, 500] & [500, 0]
\end{bmatrix}
$$

$$
M = \begin{bmatrix}
[100, 90] & [90, 70] & [70, 50] & [50, 30] & [30, 0]
\end{bmatrix}
$$

$$
M = \begin{bmatrix}
[100, 80] & [80, 60] & [60, 40] & [40, 20] & [20, 0]
\end{bmatrix}
$$
The results shows that:

(1) the grade characteristic values shows a decreasing trend from 2010 to 2017, indicating that the sustainable utilization level of water resources has a tendency to become better. The grade characteristic value of 2017 is the smallest, indicating that the sustainable utilization potential of water resources is the greatest, while the grade characteristic value of 2010 is the largest, indicating that the potential is the least. The grades from 2010 to 2017 belong to intermediate.

(2) the sustainable utilization level of water resources in Nansi Lake basin is closely related to its water resources characteristics and social and economic conditions. There are some problems in Nansi Lake basin, such as small volume of water resources, large population density, paying attention to agriculture, slow industrial development and so on, resulting in small potential for sustainable utilization of water resources. However, due to the implementation of the strictest water resources management system, the river and lake chief system and the construction of water ecological civilization, the sustainable utilization level of water resources in the Nansi Lake basin has a trend of increasing year by year.

(3) as can be seen from Table 2, the indexes that lead to the low potential of sustainable utilization are water production coefficient, per capita water resources, per capita GDP, proportion of agricultural water use and ecological environment water use, in which the first two indexes belong to Grade V and the latter three belong to Grade IV. Therefore, in order to improve the potential of sustainable utilization of water resources in Nansi Lake Basin, some measures are needed to improve the above indexes. In order to increase water production coefficient and per capita water resources, surface water storage projects should be properly built to intercept floods, and low impact development engineering should be constructed to collect rainfall; in order to increase per capita water resources, per capita GDP and reduce proportion of agricultural water use, we should control population growth, adjust industrial structure, strengthen industry and tertiary industry, and improve the water-saving level of industry and agriculture; in order to increase the proportion of ecological environment water use, the guarantee degree of ecological environment water use should be increased and the construction of water ecological civilization should be promoted.

5. Conclusion

(1) In this paper, the evaluation index system of sustainable utilization of water resources is constructed, which considers the development and utilization of water resources, social economy and
ecological environment. The evaluation grade is classified into five grades: special, strong, intermediate, light and tiny, and the classification criteria of indexes is determined, which is reliable and standardized.

(2) The VFS model can reasonably deal with the fuzzy characteristics of evaluation indexes, reflect the level of sustainable utilization of water resources objectively, and improve the credibility of the evaluation results. In addition, the VFS model has the advantages of easy to understand and strong maneuverability.

(3) Taking Nansi Lake Basin as an example, the results shows that the sustainable utilization level of water resources has a trend of improvement year by year from 2010 to 2017, which is closely related to the implementation of the strictest water resources management system, the river and lake chief system and the construction of water ecological civilization. In order to improve the sustainable utilization level of water resources, we should properly build surface water storage projects, popularize the low impact development engineering, control population growth, adjust industrial structure, strengthen industry and tertiary industry, improve the water-saving level of industry and agriculture, increase the guarantee degree of water use for ecological environment and so on.

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