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Variable fuzzy assessment of water use efficiency and benefits in irrigation district

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Abstract

In order to scientifically and reasonably evaluate water use efficiency and benefits in irrigation districts, a variable fuzzy assessment model was established. The model can reasonably determine the relative membership degree and relative membership function of the sample indices in each index's standard interval, and obtain the evaluation level of the sample through the change of model parameters. According to the actual situation of the Beitun Irrigation District, which is located in Fuhai County, in Altay City, Xinjiang Uyghur Autonomous Region, five indices were selected as evaluation factors, including the canal water utilization coefficient, field water utilization coefficient, crop water productivity, effective irrigation rate in farmland, and water-saving irrigation area ratio. The water use efficiency and benefits in the Beitun Irrigation District in different years were evaluated with the model. The results showed that the comprehensive evaluation indices from 2006 to 2008 were all at the third level (medium efficiency), while the index in 2009 increased slightly, falling between the second level (relatively high efficiency) and third level, indicating an improvement in the water use efficiency and benefits in the Beitun Irrigation District, which in turn showed that the model was reliable and easy to use. This model can be used to assess the water use efficiency and benefits in similar irrigation districts.

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Keywords: Variable fuzzy assessment; Water use efficiency and benefits; Beitun Irrigation District

1. Introduction

In recent years, China has focused on the development, utilization, conservation, and protection of water resources, and formulated a series of policies and regulations to improve the water use efficiency and benefits in irrigation districts (Ye et al., 2011), resulting in an increase in irrigation water use efficiency. However, distribution of the available water resources will change significantly in the coming decades due to an increase in the water requirements of other sectors, such as the natural environment, and a foreseen reduction in rainfall due to climate change effects in China (Cruz-Blanco et al., 2014). There is still a large gap between China and developed countries in the water use efficiency and benefits. Thus, in order to ease severe water shortage pressure in China, we should further improve the irrigation efficiency and fully explore the potential of agricultural water-saving measures (including strengthening and perfecting irrigation and water supply projects, and establishing efficient water-saving projects in the field).

Irrigation water use represents the major fresh water use in the world (Braud et al., 2013). According to the Food and Agriculture Organization, about 60% of total water resources

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all over the world are used for agricultural irrigation (Lin et al., 2012). The role of water in agricultural production is very complex and affected by many factors (Kaneko et al., 2004). Water resources utilization varies greatly across different irrigation districts in China, so it is necessary to evaluate the water use efficiency and benefits in each irrigation district with a scientific and reasonable method, which can provide a scientific basis for making decisions and organizing subsequent water conservation work. Agricultural water use efficiency is a key index in assessment of irrigation water use from the water source to the crop (Martin et al., 2004). Traditionally, field experiments are conducted to quantify and evaluate water management practices in irrigation systems (Singh et al., 2006).

There have been many studies offering methods of evaluating the water use efficiency and benefits in irrigation districts, including the fuzzy comprehensive evaluation method put forward by Wang (2011), Zhang and Fan (2001), and Ye et al. (2011); the comprehensive evaluation method based on principal component analysis used by Chen et al. (2011); the remote sensing-based method (Cruz-Blanco et al., 2014); and distributed ecohydrological modeling (Singh et al., 2006). However, these methods all have their own limitations. For the fuzzy comprehensive evaluation method, the algorithm used to process large and small values is unreasonable and some problems related to the maximum membership degree principle need to be solved (Wang et al., 2007). For the comprehensive evaluation method based on principal component analysis, the selection of different eigenvalue vector combinations may cause a wide range of fluctuations in evaluation results (Sun and Qian, 2009). In general, specific recommendations obtained from field experiments cannot be generalized to the regional level with different ecohydrological conditions (Singh et al., 2006). There is a general consensus about the importance of finding a more effective and universal way to assess the water use efficiency and benefits in irrigation districts.

Of the developed methods, the variable fuzzy evaluation method has proved to have the highest reliability and operability (Huang et al., 2013; Zhao and Chen, 2008), and it can scientifically and reasonably determine the relative membership degree and relative membership function of sample indices in the standard interval of each index (Huang et al., 2013). The variable fuzzy evaluation method has also been widely used in many fields, such as flood risk analysis and evaluation (Li et al., 2012) and reservoir water quality evaluation (Huang et al., 2013). Compared to other methods, it can be used with less quantitative information and it can simplify the mathematical process so that we can analyze complex multi-criteria problems (Zhang, 2009). However, there has been little examination of the method when applied in the evaluation of the water use efficiency and benefits in an irrigation district. Therefore, the objective of this study, with the Beitun Irrigation District (in Xinjiang Uyghur Autonomous Region, in China) as an example, was to determine the reasonable water use efficiency and to evaluate the benefits of water use in the irrigation district using the variable fuzzy evaluation method.

2. Model of variable fuzzy assessment

We assume that U is a fuzzy concept, and $\underset{\sim}{A}$ and $\underset{\sim}{A}^C$ represent the attractability and repellency, respectively. For any element u ($u \in U$), $\mu_{\underset{\sim}{A}}(u)$ is the relative membership degree of u to $\underset{\sim}{A}$, $\mu_{\underset{\sim}{A}^c}(u)$ is the relative membership degree of u to $\underset{\sim}{A}^C$, and. $\mu_{\underset{\sim}{A}}(u) + \mu_{\underset{\sim}{A}^c}(u) = 1$

If $D_{\underset{\sim}{A}}(u) = \mu_{\underset{\sim}{A}}(u) - \mu_{\underset{\sim}{A}^c}(u)$, $D_{\underset{\sim}{A}}(u)$ is defined as the relative difference degree of u to $\underset{\sim}{A}$ according to Chen et al. (2011), and then we have

$$\mu_{\underset{\sim}{A}}(u) = \left(1 + D_{\underset{\sim}{A}}(u)\right) \Big/ 2 \tag{1}$$

If $V = \{(u, D_{\underset{\sim}{A}}) | u \in U, D_{\underset{\sim}{A}} \in [-1, 1]\}$, $A_+ = \{u | u \in U, 0 < D_{\underset{\sim}{A}}(u) \le 1\}$, and $A_- = \{u | u \in U, -1 < D_{\underset{\sim}{A}}(u) \le 0\}$, then V is defined as a variable fuzzy set of U, and A_+ and A_- are defined as the attraction domain and exclusion domain of V, respectively.

We assume that $X_0=[a, b]$ is the attraction domain of V on the real axis, $X=[c, d]$ is the range domain containing X_0 ($X_0 \subset X$), M is the point of $D_{\underset{\sim}{A}}(u) = 1$ in the attraction domain $[a, b]$, and x is a random point. The positional relationships among points x and M and domains $[a, b]$ and $[c, d]$ are shown in Fig. 1.

When $x \in [c, M]$, $D_{\underset{\sim}{A}}(u)$ can be calculated by

$$\begin{cases} D_{\underset{\sim}{A}}(u) = \dfrac{x-a}{M-a} & x \in [a, M] \\ D_{\underset{\sim}{A}}(u) = -\dfrac{x-a}{c-a} & x \in [c, a) \end{cases} \tag{2}$$

When $x \in (M, d]$, $D_{\underset{\sim}{A}}(u)$ can be calculated by

$$\begin{cases} D_{\underset{\sim}{A}}(u) = \dfrac{x-b}{M-b} & x \in (M, b] \\ D_{\underset{\sim}{A}}(u) = -\dfrac{x-b}{d-b} & x \in (b, d] \end{cases} \tag{3}$$

When $x \notin [c, d]$, $D_{\underset{\sim}{A}}(u)$ can be expressed as

$$D_{\underset{\sim}{A}}(u) = -1 \tag{4}$$

It is hypothesized that there is a sample index matrix $\boldsymbol{X}$ for identifying the water use efficiency and benefits in an irrigation district:

$$\boldsymbol{X} = (x_{ij}) \tag{5}$$

where x_{ij} is the ith index of the jth sample; i=1, 2,$\cdots$, m, where m is the total number of indices; and j=1, 2,$\cdots$, n, where n is the total number of samples.

Every index can be evaluated by k levels and a matrix is obtained that contains $m \times k$ index standard values:

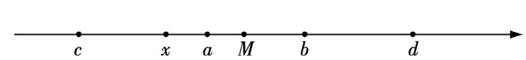

Fig. 1. Positional relationship among points x and M and domains $[a, b]$ and $[c, d]$.

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