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AGWAT-4573; No. of Pages 14
ARTICLE IN PRESS
Agricultural Water Management xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Agricultural Water Management
journal homepage: www.elsevier.com/locate/agwat

# An Improved Analytic Hierarchy Process Method for the evaluation of agricultural water management in irrigation districts of north China

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ARTICLE INFO

*Article history:*
Received 3 February 2016
Received in revised form 30 July 2016
Accepted 1 August 2016
Available online xxx

*Keywords:*
Agricultural water management
Irrigation district
Index system
Improved AHP
Fuzzy comprehensive evaluation

ABSTRACT

Agricultural water management is the core part of agricultural efficient water use in irrigation districts, which provides basic guarantee and decision-support for improving the efficiency of water production. This study was conducted in three typical irrigation districts in Huang-huai-hai river basin of north China. The evaluation index system of agricultural water management in irrigation districts was established which included technology index, engineering index, management index, environment index and economic index, classified 5 sorts of second-grade indices, 14 third-grade indices and 35 fourth-grade indices. The weight of each index was confirmed through improved AHP method. The grades of agricultural water management of Fenhe, Shijin and Renmin Shengliqu irrigation districts in Huang-huai-hai riverbasin were obtained using Grey Correlation method and Fuzzy Comprehensive Evaluation method. Results showed that the evaluation indices ranked according to the descending order of their weights as engineering index, 0.2147; management index, 0.2138; technology index, 0.2128; economics index, 0.1797; environment index, 0.1791 in the criterion level. The engineering and management index were the most two important factors which influenced the agricultural water management in irrigation districts. The grades of Fenhe, Shijin and Renmin Shengliqu irrigation districts were good, good and average, respectively. The study provides a theoretical basis in improving the level of agricultural water management and water use efficiency in irrigation districts of north China.

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## 1. Introduction

In China, agriculture is not only the foundation of national stability, but also the precondition of economic and social development. Irrigation districts, as management units for irrigation water allocation, have great responsibility to promote the development of agriculture, and ensure the grain output and the food security. According to statistics, the total water supply of large irrigation districts in China reached 172.5 billion $m^3$ (compared to 222 billion $m^3$ to the combined industrial and urban water use), which accounts for 31.7% of the total water supply (11.4% of the total water supply to the industry and urban areas)in China. Therefore, large irrigation districts play an important role in allocating water resources spatially into different areas of river basins. With available water supply continuously reduced annually, the implementation of the unified management of the river basin and the unified distribution of water rights are needed. Agricultural water management is an important component in the management practices of irrigation districts to achieve efficient use of water resources and promote high agricultural yield through appropriate water diversion and distribution, and improved field irrigation practices. Thus, it becomes increasing important for conducting research related to improving agricultural water management practices to alleviate the water shortage in the current irrigation districts.

Many previous works about agricultural water management practices had been addressed in the last two decades. The purpose of the development in improving agricultural water management in the past was mainly to strengthen agricultural productivity and overcome poverty and hunger (Chen and Ravallion, 2007). At present, the objective has gradually been switched to develop agricultural water conservancy (Gordon et al., 2010) and promote rural economy (Molden, 2007) to increase farmers' income (Namara et al., 2010), to maintain ecological balance (De Fraiture et al., 2010), to cope with climate change (Barker and Molle, 2004) under the situation of water resources shortage, and to meet the increasing demand for food because of the increasing population in the world. In the meanwhile, agriculture, rural development, environment, water supply and drainage of irrigation and production technology (Xu et al., 2010) are closely related with the water use, the main economic situation and macroeconomic policy as well (World

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http://dx.doi.org/10.1016/j.agwat.2016.08.002
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Please cite this article in press as: Sun, H., et al., An Improved Analytic Hierarchy Process Method for the evaluation of agricultural water management in irrigation districts of north China. Agric. Water Manage. (2016), http://dx.doi.org/10.1016/j.agwat.2016.08.002

Bank, 2006). Cheng and Wang (2010) studied the development, characteristics and influencing factors of irrigation management in Yellow River Basin of China. Wang (2012) proposed that the achieving the transformation from water supply management to water demand management is the key to change the water management concept with special attention to the transition from decentralized water resources management system to integrated water resources management system. Ju et al. (2012) constructed the theoretical framework of water demand management in irrigation districts based on the analysis of challenges faced by large irrigation districts. However, there were few studies on the combination of theoretical analysis and systematic evaluation, given that most of the previous studies were about the existing problems and discussion on the corresponding reform measures. Therefore, it is important to develop the comprehensive approach for evaluating agricultural water management in irrigation districts.

There are many comprehensive evaluation methods used in assessing efficiency of irrigation districts. Such as, principal component analysis, approximate ideal point method (Zhu et al., 2004; Ke, 2008), extension evaluation method (Sun et al., 2006; Chi et al., 2008; Ma et al., 2009), projection pursuit method(Wang et al., 2002; Feng et al., 2005; Jiang and Cao, 2006; Luo et al., 2012), grey correlation method (Men et al., 2003; Li et al., 2006), fuzzy comprehensive evaluation method (Jin et al., 2006; Zhang et al., 2008; Qi et al., 2008; Zhao et al., 2012), and neural network method (Xu and Lei, 2001; Gao et al., 2003). Among those, grey correlation method developed by Deng (1982) and fuzzy comprehensive evaluation method developed by Zadeh (1965) have been widely used and proved effective in the evaluation of irrigation districts.

To attain the weight of indices is a prerequisite for comprehensive evaluation, since it has a decisive influence on the evaluation results. The rationality of index weight is closely related to the credibility of evaluation results and should be determined reasonably and effectively. Analysis hierarchy process (AHP), proposed by Saaty (1977) and widely used in the calculation of the weight of evaluation index system with the unique operation method, is a flexible and simple statistical method of multidimensional objective policy making, and can turn qualitative indicators to quantitative ones in order to make complex problems hierarchical and systematic (Saaty, 1980, 2004; Wu and Li, 2004; Cai and Lin, 2001; Xiong and Cao, 1992). Previous studies have showed the potential and effectiveness of AHP applied to irrigation project evaluation, and on the other hand, there would be still room to improve the AHP model toward better evaluation of the irrigation project (Karamouz et al., 2002; Okada et al., 2008 Okada et al., 2008).The great advantages of the AHP lies in its ability to handle complex real life problems and with its ease of use (Alphonce, 1997). However, the accuracy and reliability of the calculated weight by AHP will be affected by the index structure since the difference in hierarchical structure of index system and the number of indices, which comes up with a phenomenon that is extremely logic. Accordingly, the analytic hierarchy process is improved in this study by considering hierarchical structure and the number of indices in an effort to make the results more reasonable.

This study was conducted in three typical irrigation districts of Huang-huai-hai river basin, i.e. Fenhe irrigation district, Renmin Shengliqu irrigation district and Shijin irrigation district, and the paper was organized as follows: (1)the evaluation indices were screened and determined by theoretical analysis and Delphi method. Then the evaluation index system of agricultural water management in irrigation districts was established; (2) the weight of each index in the evaluation index system of agricultural water management practices in irrigation districts was evaluated through the improved AHP method; (3) the agricultural water management level of three typical irrigation areas in Huang-huai-hai river basin were evaluated by using Grey Correlation Analysis method and Fuzzy Comprehensive Evaluation method; (4)the measures to improve the agricultural water management level for different irrigation districts were proposed.

## 2. Materials and methods

### 2.1. Study area

Huang-huai-hai river basin is the general designation of the Yellow River Basin, Huaihe River Basin and Haihe River Basin, which spans 14 provinces and two mega cities of Beijing and Tianjin (Shao et al., 2012). The total area of the basin is about 1.383 km$^2$, accounting for 14.3% of the total area in China, and 31.5% of the total area of the whole basin in China. Continuous wet or dry years often appear in this basin, and precipitation in the area is unevenly distributed both spatially and temporally. The cultivated land area and GDP of this region account for around 33% of the entire country, while the total water resources only account for 7.2%. Water resources per capita are only 465 m$^3$, which is far below the warning limit recognized internationally. The utilization rate of surface water has reached 72%, 37% and 78% in the three basins respectively, which are already over or approaching 40% of the warning line (China Institute of Water Resources and Hydropower Research, 2003; http://www.mwr.gov.cn/zwzc/hygb/szygb). The groundwater overdraft problem is serious with apparent annual groundwater level decline. With the rapid increase in population and the development of social economy, the utilization of water resources continues to increase and the available water supply is unable to meet the demand for water in some areas of the region. The three typical irrigation districts of Huang-huai-hai river basin, including Fenhe irrigation district in Shanxi Province of the Yellow river basin, Renmin Shengliqu Irrigation District in Henan Province of the Yellow River Basin and Shijin irrigation district in Hebei Province of the Haihe river basin, were selected in this study and their locations are shown in Fig. 1. The irrigation area of Fenhe Irrigation District, Renmin Shengliqu Irrigation District and Shijin Irrigation District are $99.7 \times 10^3$ hm$^2$, $99.2 \times 10^3$ hm$^2$ and $162.7 \times 10^3$ hm$^2$, respectively. The three irrigation districts were selected mainly based on consideration that all three typical districts are well-known large-scale irrigation districts, and the three districts more or less represent three typical stages of water management level of large-scale irrigation districts in China in the sense of adopting advanced technologies, equipment and policies. Fenhe Irrigation District has recently introduced the Australian Rubicon irrigation technology, thus can be seen as an example of modern irrigation districts; the Renmin Shengliqu Irrigation District is the first large scale gravity irrigation district and irrigation water diverted from the Yellow River, thus represents traditional districts; the irrigation management of Shijin Irrigation District is the Participatory Irrigation Management of Water Users' Association, thus represents those districts with reformed water management policies.

### 2.2. Methods

#### 2.2.1. Delphi method

In order to select the most important index to evaluate the irrigation management level, the Delphi survey among irrigation experts and farmers participating in the agricultural water management was conducted in this study. The Delphi technique was developed during the 1950s and has become a widely used tool for measuring and aiding forecasting the potential benefits of decision making in a variety of disciplines. Four key features may be regarded as necessary for defining a procedure as a 'Delphi'. These are: anonymity, iteration, controlled feedback, and the statistical

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