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Developing an integrated risk management framework for agricultural water conveyance and distribution systems within fuzzy decision making approaches

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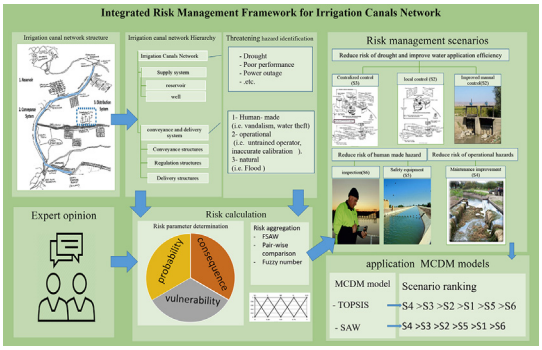
HIGHLIGHTS

- Inefficient agricultural water systems have been led to significant operational water losses.
- Canal network as the primary agricultural water distribution systems is exposed to a variety of hazard.
- Risk assessment of the hazards, evaluate the possibility of water distribution system failures.
- A risk management framework for selecting irrigation modernization strategies is developed.
- The framework is employed for risk management of the Qazvin irrigation canal network.

GRAPHICAL ABSTRACT



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ABSTRACT

Irrigation canal networks, as the primary agricultural water conveyance and delivery systems, are exposed to a variety of hazards affecting the water distribution processes. This study, for the first time, develops a comprehensive risk management framework for the canal network through a Fuzzy Hierarchical method. In this regard, the risk is analyzed by a combination of probability, consequence, and vulnerability against identified hazards based on the hierarchical framework. The developed model is based on fuzzy numbers to consider the uncertainties arise from experts' opinion. To aggregate the calculated risk in the hierarchical framework, the Fuzzy Simple Additive Weighting (FSAW) approach was employed. To enhance the reliability of the water distribution system and decrease the risk of failure, six risk management alternatives are proposed based on the risk assessment results and the most significant hazards. To prioritize managerial scenarios, two sets of criteria were selected including quantitative criteria (consisting of cost of operation and risk reduction) and a qualitative set (compromising social and operational criteria). The risk management scenarios were prioritized based on two rational multi-criteria decision-making (MCDM) methods of a Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW). Regarding different degrees of importance of the criteria, a pair-wise comparison was conducted by a group of experts to determine the relative weight of the criteria. According to the risk assessment results, the riskiest hazards are poor maintenance, seepage, unexpected event, drought, and vandalism of the structure. Moreover, employing the MCDM model in risk-based

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decision-making reveals that "maintenance improvement" is ranked as the first scenario, with score values of 0.851 and 0.237 employing the SAW, and TOPSIS approaches, respectively.

1. Introduction

Performance of the irrigation sectors, as the most significant water users in developing countries, needs immediate improvements due to increasing demands for crop production and competition for water allocation between agricultural and non-agricultural sectors (Kanooni and Monem, 2014). Practical measures to achieve this goal have been concentrated on two broad categories of on-farm and off-farm activities. The former has focused on activities which consist of cropping pattern optimization (Amini Fasakhodi et al., 2010; Montazar et al., 2010; Garg and Dadhich, 2014), and application of modern technologies at the farm scale to ensure proper water management within the farms (Ismail and Almarshadi, 2013; Hassan-Esfahani et al., 2015). However, in off-farm practices, application of automatic control systems to minimize operational water losses and increase flexibility of water distribution has been reported (Horváth et al., 2010; Van Overloop et al., 2010; Xu et al., 2011; Fele et al., 2014; Maestre and Negenborn, 2014; Horváth et al., 2015). Moreover, applying advanced operational strategies including in-line water storage (Hashemy Shahdany et al., 2012), and fair water distribution along the main canal (George et al., 2011a, 2011b; Shahdany et al., 2016), using automatic techniques, constitute operational performance improvements at this level. However, it should be noted that the first task required in providing efficient agricultural water management is a comprehensive assessment of the current weakness and strength of the conveyance and delivery systems.

This evaluation requires the specification of the real potential of the system in achieving any water management objectives, regardless of on-farm and off-farm activities. The performance appraisal methods used currently are based on qualitative and quantitative assessments (Montazar et al., 2013). These methods consist of a wide range of indicators considering different aspects including managerial, social, environmental, and economic indices. Using the approaches mentioned above, the performance of the system is compared to relevant indicators with the assigned targets. Despite the advantages of these methods, however, there are some limitations which have influenced the appraisal results. The first of these is the sectional accomplishment of the evaluation projects which do not lead to a comprehensive assessment of irrigation networks due to limitations in financial resources. The next limitation is ignoring the various threatening hazards which influence the performance of the system or even cause failure in water supply, conveyance or delivery procedures under present conditions. In another words, the conventional appraisal methods are not capable of recognizing the future challenges of the irrigation district. Moreover, due to the lack of a multi-faceted perspective in these methods, system failure prevention may not be achieved. In these conditions, disorganized maintenance activities are proposed based on the uncoordinated performance evaluation projects within the irrigation districts. Furthermore, funding and on-time maintenance implementation are serious obstacles, where mostly deferred maintenance is not effective and comprehensive rehabilitation is needed (Donaldson, 2013). Therefore maintaining the system in desirable performance conditions and providing continuous service at lower cost is preferable rather than an approach focused on repair and maintenance. To deal with the limitations mentioned above, the risk-oriented assessment project is proposed which has been extensively carried out within related infrastructure, such as urban water supply and wastewater systems.

Risk assessment by combining the probability and consequence of system failure and vulnerability of components against the threatening hazards, evaluates the possibility of failure in the system (Torres et al., 2009). Different studies note the advantages of risk assessment in water supply systems. Fares and Zayed (2010) used the fuzzy hierarchical system to evaluate the failure risk considering 16 failure factors. Roozbahani et al. (2013) presented an integrated risk assessment framework for an urban water system in Urmia city, Iran, to evaluate the risk associated with the water supply system, treatment plant, and water distribution system. The fuzzy numbers were used to consider uncertainty in the inputs. Macey et al. (2014) developed a risk-based framework for rehabilitation planning in Colorado Springs. The risk was based on probability and consequence and the risk was determined based on the risk matrix.

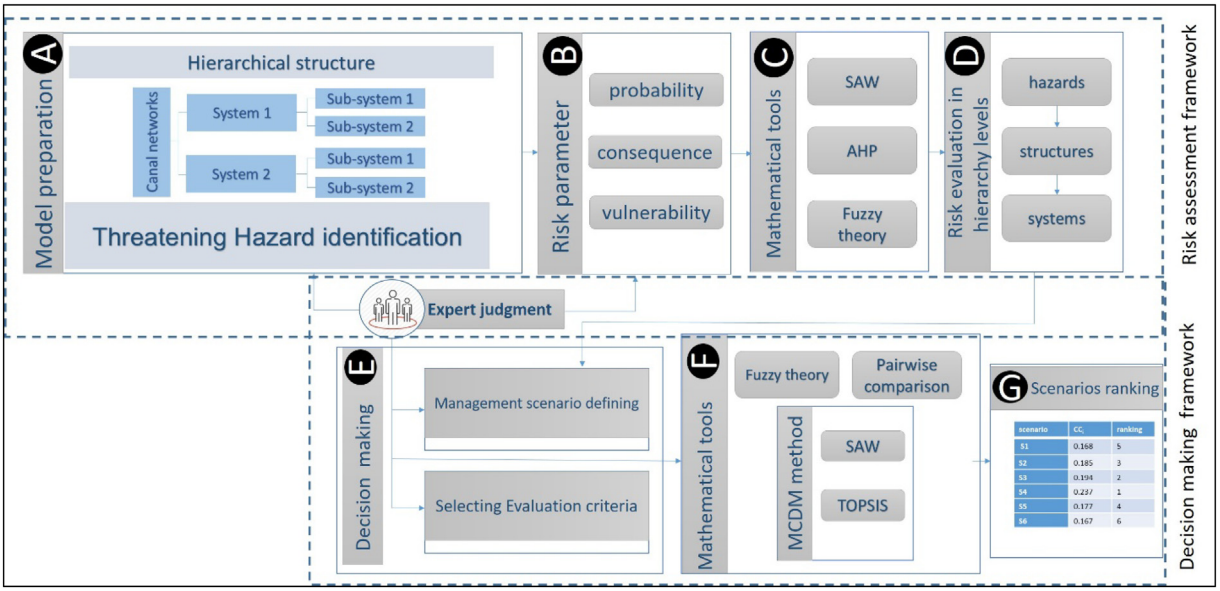

Fig. 1. The proposed risk management framework.