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Decision-making in irrigation networks: Selecting appropriate canal structures using multi-attribute decision analysis

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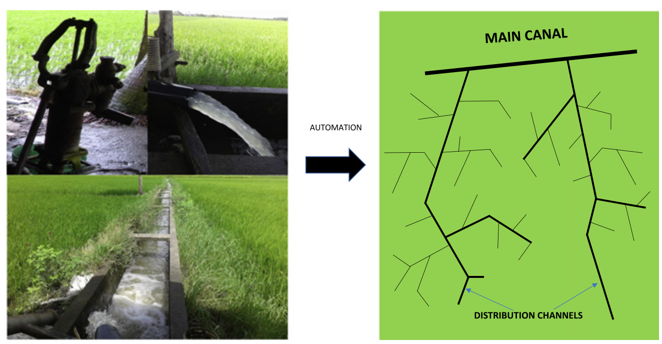
HIGHLIGHTS

- Agriculture is one of the highest users of water among all water consumers.
- Inefficient water distribution in irrigation networks is due to many complex issues.
- Automation of flow control structures can improve water delivery efficiencies.
- A decision analysis framework for selecting irrigation structures is developed.
- The utility of the framework is illustrated via analysis of the Qazvin network.

GRAPHICAL ABSTRACT



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ABSTRACT

The stiff competition for water between agriculture and non-agricultural production sectors makes it necessary to have effective management of irrigation networks in farms. However, the process of selecting flow control structures in irrigation networks is highly complex and involves different levels of decision makers. In this paper, we apply multi-attribute decision making (MADM) methodology to develop a decision analysis (DA) framework for evaluating, ranking and selecting check and intake structures for irrigation canals. The DA framework consists of identifying relevant attributes for canal structures, developing a robust scoring system for alternatives, identifying a procedure for data quality control, and identifying a MADM model for the decision analysis. An application is illustrated through an analysis for automation purposes of the Qazvin irrigation network, one of the oldest and most complex irrigation networks in Iran. A survey questionnaire designed based on the decision framework was distributed to experts, managers, and operators of the Qazvin network and to experts from the Ministry of Power in Iran. Five check structures and four intake structures were evaluated. A decision matrix was generated from the average scores collected from the survey, and was subsequently solved using TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method. To identify the most critical structure attributes for the selection process, optimal attribute weights were calculated using Entropy method. For check structures, results show that the duckbill weir is the preferred structure while the pivot weir is the least preferred. Use of the duckbill weir can potentially address the problem with existing Amil gates where manual intervention is required to regulate water levels during periods of flow extremes. For intake structures, the Neyrpic® gate and constant head orifice are the most and least preferred alternatives, respectively. Some advantages of the Neyrpic® gate are ease of operation and capacity to measure discharge flows. Overall, the application to the Qazvin irrigation network demonstrates the utility of the proposed DA framework in selecting appropriate structures

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for regulating water flows in irrigation canals. This framework systematically aids the decision process by capturing decisions made at various levels (individual farmers to high-level management). It can be applied to other cases where a new irrigation network is being designed, or where changes in irrigation structures need to be identified to improve flow control in existing networks.

1. Introduction

Irrigation is one of the highest users of water among all other water consumers (Isapoor et al., 2011). For example, in the United States irrigation is second only to the thermoelectric industry and accounts for 37% of freshwater withdrawals (Kenny et al., 2009). Irrigation consumption is also substantially higher in arid regions where agricultural production is only possible with irrigation. For instance, in West Asian and North African countries, irrigated agriculture accounts for 75% of water consumption (Oweis and Hachum, 2006) while in Uzbekistan in Central Asia, irrigation uses 90% of available surface water (UNFCC, 2009). In Iran, it is estimated that over 94% of available water from all sources is used in irrigated agriculture (Alizadeh and Keshavarz, 2005).

In view of the increasing demand for water against a limited supply and the present threats of climate change, there is an urgent need for better water management practices and improved water use efficiencies in irrigation networks (Conrad et al., 2007). Automation of structures is one of the most desired strategies for improving water-use efficiencies in irrigation canals; for example, upstream manipulation of intake structures to regulate downstream water levels can be most efficiently done with automation (Gómez et al., 2002; Burt et al., 1998). Where automated flow regulation is required, motorized gates equipped with control devices are required (Aisenbrey et al., 1978). Since water in canals can be treated as a series of pools separated by control structures (Van Overloop et al., 2005), it is possible to design centralized or decentralized logic control for flow regulation.

Ideally, schemes for automating irrigation infrastructure assume that structures can be integrated seamlessly. In reality, the integration of structures, whether old or new or a mix of both, is highly complex and should be taken in the context of existing irrigation system level. Further, it requires an understanding of local settings (e.g., age of structure and operator skills) and accurate hydrological information at the appropriate scale (Conrad et al., 2007). In particular, the process of selecting intake (structure for directing water from source to the irrigation system) and check (structure for regulating water level in canals) structures involves different levels of decision makers (e.g., top-level management, irrigation personnel, and farmers) who must rank alternatives based on constraints and predefined evaluation criteria. These criteria often include technical, environmental, social, and economic considerations. For example, a check structure may exhibit excellent hydraulic performance in automation simulations but it may be too complex to operate and maintain for farmers. Energy requirements for full automation should also be within the capacity of the local electric grid (Massey et al., 1983). Some structures are also more prone to tampering than others (Vos, 2005), or are more costly to operate.

Given the various and sometimes conflicting considerations for selecting irrigation flow control structures, a systematic approach for decision analysis is needed to assist decision makers in selecting an optimal solution. In this paper, we apply the multi-attribute decision-making (MADM) methodology to develop a decision analysis (DA) framework for evaluating, selecting, and ranking check and intake structures for automated operation in irrigation canals (Fig. 1). MADM techniques have been applied in prioritization studies involving various disciplines such as urban watershed management (Chung et al., 2011) water and wastewater treatment (Pagsuyoin et al., 2015; Aragonés-Beltrán et al., 2009), health care, and infrastructure risk assessment (Behzadian et al., 2012). In the current application, we formulate a set of desired structure attributes and use them as evaluation criteria for structure selection. The proposed decision framework combines the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) ranking method with Entropy method for allocating optimal attribute weights. To demonstrate its utility, the DA framework was applied to analyze the Qazvin irrigation network, one of the oldest and most complex irrigation networks in Iran.

2. Methodology

2.1. Flow control structures

In an irrigation system, water drawn from a source passes through a series of canals (channels) before it is delivered to farm fields. The entrance section from the channel to the farm field is referred to as the field intake or turnout. Flow control structures are constructed at the intake (intake structure) and within the canals (check structure) to either regulate flow through the structure, control upstream water elevation, or perform both. To date there are various types of structures for water conveyance and distribution in farms, many of which are costly to construct and operate, resulting in higher irrigation costs per unit farm output. Design and selection criteria for flow control structures have been proposed but most of them focus on hydraulic considerations (e.g., downstream topography, flow rate) (Takasu and Hirose, 2009).

2.1.1. Intake structures

Flow control structures in field intakes are classified based on water source (e.g., river, ponds, reservoirs), type of flow diversion (e.g., surface, subsurface, mixed), or method for regulating flow (e.g., breach, gated,

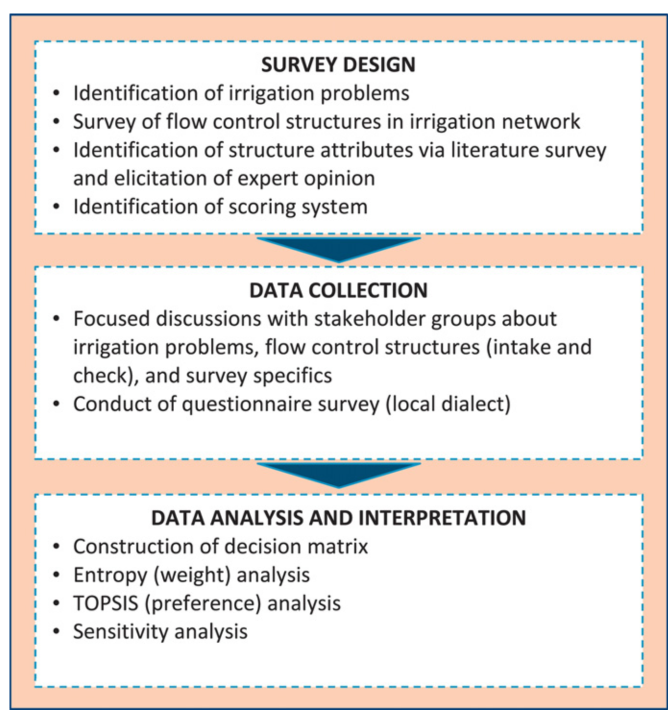

Fig. 1. Decision framework for irrigation structure selection.