Risk management of agricultural water supply and distribution systems using FDBN model and MULTIMOORA technique

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Introduction

Changes made to the environment by people or any shifts in climate patterns affect water volume demand in agricultural production and raise the risk of agricultural product failure. A risk assessment model is needed to improve the condition of agricultural water systems to use water resources during operation efficiently and to meet demands. In previous research, various models have been implemented to investigate the risk (Abedzadeh et al. 2020). Among them, Bayesian Networks have had effective results (Wang et al. 2022). Here, a Fuzzy Dynamic Bayesian Network (FDBN) as a superior version of BNs is used to model the risk assessment of agricultural water systems. FDBN is utilized to model causal and temporal relations between different system components and results obtained from FDBN are used to implement risk management approach.

Research on risk management in water systems has been conducted from different perspectives with different techniques (Orojloo et al. 2018; Roozbahani et al. 2012). In this study, various risk management scenarios of the Roodasht irrigation district, Esfahan, Iran, are defined. The capability of scenarios are assessed in multiple aspects of economic, social, environmental, and technical criteria. The applicable scenarios are selected with a MULTIMOORA as a multi-criteria decision making method and presented to the operators and network manager.

Materials and methods

Risk assessment is based on three main terms, which are defined due to hazards that threaten the system. These terms are the probability of hazard occurrences, systems' vulnerability against the hazard, and hazards' consequences. In this study, the Roodasht irrigation district was selected as a case study which is in Iran. This system is threatened by three hazards. These are Drought, Improper Performance of the Ditch-Riders (IPDRs) and Operational Losses (OL). The risk terms were calculated using hydraulic and hydrological indices based on the nature of the system and hazards (Bozorgi et al. 2021). The risk assessment was modelled by the FDBN method.

Risk management scenarios: In the next step, different risk management scenarios were identified by using expert opinion and historical case study research. These scenarios were classified into four types: non-structural, structural, automatic control, and integrated scenarios. Non-structural approaches improve network operation in water scarcity situations by using operational experience. The focus is to enhance the traditional way of manually or automatically adjusting water level structures. The four scenarios which were considered in this group are Scheduled water delivery (Scn.1), Operation method to reduce dewatering time (Scn.2), Inflow fluctuation prediction (Scn.3), Increasing the intake recharge and reducing the flow time in the irrigation canal (Scn.4). The Structural scenario (Scn.5) is the modernization or replacement of hydraulic structures. Integrated scenarios were made up of two structural and non-structural strategies. All necessary activities in non-structural scenarios (4 scenarios stated (Scn.6-9)) are performed in integrated scenarios, along with the required changes in catchment structures. In Automated control, the Model Predictive Control (MPC)(Scn.10) system and the decentralized automatic control system - Proportional-Integral Controller (PI) (Scn.11) are two selected scenarios in this group.

Criteria: In this step, criteria were defined to evaluate the performance of risk management scenarios.

These are the technical, economic, social, and environmental factors. The technical criterion is the potential of each scenario to reduce the system's risk. This is the difference between the average risk of the system in baseline (current situation) and the application of each scenario which was evaluated with the FDBN model. The economic criterion includes two sub-criteria: (a) the cost of implementing each scenario, (b) the agricultural benefits of modernizing the surface water distribution system. The next criterion is social, divided into two sub-criteria: (a) increased employment, which is considered by increasing the area under surface water irrigated, (b) equity of water delivery, a metric that measures the proportion of the amount delivered vs. required over time. The last one is environmental: (a) reduction of groundwater withdrawal, (b) saving energy by reducing groundwater withdrawal. These criteria were weighted through the AHP method. A questionnaire is designed and distributed among a few experts to collect their opinions. This questionnaire is made of the pairwise matrix, which is compared criteria two by two. Eventually, the best scenario(s) was selected by utilizing MULTIMOORA as a multi-criteria decision making method.

Results and concluding remarks

In this study, the risk management scenarios of the Roodasht irrigation district were evaluated according to different criteria. The best scenarios will be chosen with MULTIMOORA method. The accuracy of modelling risk assessment with the designed FDBN model is equal to 0.90. The results of applying risk management scenarios in the FDBN model show that the average risk of the system in the High category decreases by 13.36%. The decision matrix of different scenarios and criteria is illustrated in Table 1. The results show that PI and MPC as automated control scenarios are the best options, and then integrated scenarios (structural and scheduled water delivery, inflow fluctuation prediction, increasing the inlet recharge, and reducing the flow time in the irrigation canal) are the following options.

Table 1. Decision matrix.

Scn.	Tec.	Economic		Social		Environmental		**Rank**	Scn.	Tec.	Economic		Social		Environmental		**Rank**
	SubCrt:	a	b	a	b	a	b			SubCrt:	a	b	a	b	a	b	
W	0.43	0.08	0.09	0.13	0.10	0.12	0.03										
1	5.8	40.2	974.4	1832	8	7.30	3933.2	***6***	7	6.5	83.6	628.2	1181	9	4.70	2532.7	***9***
2	5.5	40.2	461.5	866	9	3.44	1851.1	***10***	8	7.9	84.6	864.1	1623	9	6.98	3759.4	***4***
3	5.6	41.1	633.3	1193	9	4.74	2554.4	***8***	9	6.1	83.7	1200.0	2257	9	9.05	4870.4	***5***
4	5.1	40.2	812.8	1528	9	6.11	3291.0	***7***	10	11.4	121.2	2869.2	5392	3	21.92	11802.7	***2***
5	4.7	43.5	297.4	561	10	2.28	1227.3	***11***	11	9.8	84.8	3092.3	5813	6	29.05	15640.1	***1***
6	6.8	83.6	1433.3	2693	8	10.76	5791.3	***3***									

The obtained results show that the top scenarios offer two categories of solutions to network managers. First is automated solution in which hydrodynamic flow simulators calculate the amount and duration of opening/closing hydraulic structures, and the motors adjust each structure. Hence, the operator's job is limited to monitoring the operation. Second, integrated solutions can be done by launching a simple telemetry system between the hydrometric station and the operation office, increasing the number of daily operations shifts and the inspection process. According to these results, decision-makers and network operators can use this model to clarify the conditions of the irrigation network when faced with various hazards that threaten the components of the system and make the best decision in risky situations.

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