Modeling the Dispute Settlement of Reservoir In View of the Water Quality Issues: A Novel Hybrid Group Game Theory-Fuzzy Logic Approach

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Research Article

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Posted Date: June 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-246846/v1>

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Modeling the Dispute Settlement of Reservoir In View of the Water Quality Issues: A Novel Hybrid Group Game Theory-Fuzzy Logic Approach

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Abstract

To choose the best policy of the water resources allocation, considering both the quantitative and qualitative factors based on the possible uncertainties, there has always been a significant problem in the dry lands from perspectives of the decision makers. In this paper, using Game Theory concept, a novel hybrid approach of the Game Theory based fuzzy logic is proposed to reconcile conflicts among stakeholders of dam reservoirs who have their own different strategies and utilities to choose the best policy in order to gain the highest profit regarding the situations they deal with. In the proposed method, after the fuzzification of decision makers' strategies, a matrix called a "priority matrix" is formed in which a combination of their strategies and priorities is presented as the matrix elements. Based on the concept of Nash equilibrium, an optimized scenario is elected from among the bargaining scenarios constructed via the integrated strategies. This method has the privilege of providing a game space in which a large variety of strategies and priorities of many decision makers can be modeled in a fuzzy space of variables to reach a point of agreement. In this study, the 15-Khordad Dam of Iran is selected as a

case study area which faces problems such as salinity, low quality water, and conflicts among stakeholders. The results of the study indicated that the proposed method could be led to an optimized strategy for the water resources allocation.

Keywords Game Theory, Fuzzy Logic, Conflict Resolution, Nash Equilibrium, Water Quality

1 Introduction

In recent decades, with the advent of technology, the population growth has led to an ever-increasing demand for water resources, but climate change and human intervention have tremendously affected the availability of high quality water resources. One of the most substantial challenges for dam reservoir management is the operational policy optimization for both quality and quantity of water resources. This is a multi-criteria decision-making problem where the decision makers are required to choose the best strategies based on their utilities and priorities. These strategies not only are usually in contrast to each other, but also are affected by the rivals' strategies. In this regard, Game Theory can systematically analyze such situations through setting an objective function in order to enhance the individual utility of each player. However, the objective functions are often accompanied inevitably by natural uncertainties which can affect the payoffs of the decision makers. The source of such uncertainties depends either on the structure of the conflict resolution model, or on the lack of the information of the players in the Theory of Game. Although, technically speaking, the value of such uncertainties can be

reduced by some initial assumptions such as rational behavior of the players; the application of fuzzy logic is more effective in introducing the uncertainties.

In the last decades, numerous studies have investigated the efficiency of the Game Theory for conflict resolution in the field of water resources management. Madani et al. (2010) reviewed the applicability of the Game Theory to water resources management and conflict resolution problems via non-cooperative games. They illustrated the way that the dynamic structure of water resource problems and game evolution might affect the behavior of the stakeholders in different intervals of the conflict. Considering the application of the fuzzy Game Theory in the management of water resources, Kerachian et al. (2010) proposed a fuzzy bargaining model based on Rubinstein Theory to resolve conflicts among different water users in an urban region in Tehran, Iran. Sadegh and Kerachian (2011) also applied fuzzy cooperative games for the optimal allocation of available water resources and associated benefits to water users in a river basin. Abdel-Elmdoust and Kerachian (2012) utilized the fuzzy cooperative games for efficient water allocation among water users in both inter-basin and intra-basin water allocation problems.

Some other applications of Game Theory in water resources management are as follows. Kuchukmehmetoglu (2012) introduced a composite water resources allocation approach that integrated both Game Theory and Pareto Frontier concepts to investigate an acceptable and viable solution; set over the Pareto Frontier surface via the Game Theory based rationality constraints. Madani and Hoshyar (2014) developed a Game Theory-Reinforcement Learning (GT-RL) method for determining the optimal operation policies in multi-reservoir systems with respect to fairness and efficiency criteria. As the first step

to underline the utility of the GT-RL method in solving complex multi-agent multi-reservoir problems without a necessity for developing compound objectives and weight assignment, the proposed method is applied to a hypothetical three-reservoir three-agent system. Kicsiny et al. (2014) proposed a dynamic game-theoretical model for a conflict solution. This model is a deterministic continuum-strategy two-player discrete-time dynamic Stackelberg game with fixed finite time duration and closed-loop information structure. Lee (2012) applied the Game Theory to scrutinize the strategic interaction between the economic development and environmental protection in the variety of different land-use types. This methodology was illustrated in a case study of multi-objective watershed management in the Tseng-Wen reservoir in Taiwan. Recently, Varouchakis et al. (2017) proposed a zero-sum game to set the best tariff policy so as to save water under the implementation of more meticulous measures. Accordingly, they introduced municipal enterprise for water and sewage of china and the residence of the city as the decision makers as well. They also developed three scenarios to diminish the fixed charges and increase the volumetric charges. Khorshidi et al. (2019) fostered a Leader-Follower Game (LFG) based on multi-objective optimization model to determine the optimum 12-month operation policy of a reservoir in potential future dry periods. They used the concept of Conditional Value at Risk (CVaR). The minimization of CVaRs of storage loss and agricultural and environmental deficits along with maximization of planned allocation to agricultural sector were considered as Leader's objectives; while the followers tried to maximize their share of water rights using Nash bargaining method. They used the model of the operation policy in Dorudzan basin in Fars province, southwestern Iran. Chen et al. (2020) promoted an evolutionary game analysis of

tripartite cooperation strategy under mixed development environment of cascade hydropower stations. Norouzi khatiri et al. (2020) surveyed a new multi-purpose method to reach a compromise among different stakeholders by determining optimal social policies and sustainable hydro-environmental management of underground water resources.

In other prominent research efforts, studies have been carried out by the application of Game Theory to the quantitative and qualitative exploitation of dam's reservoirs. Kerachian and Karamouz (2007) developed the optimal operating rules for water quality management in river–reservoir systems via combining a water quality simulation model and a stochastic GA-based conflict resolution technique. As the different decision-makers were involved in the water quality management in river–reservoir systems, a new stochastic form of the Nash Bargaining Theory was applied to resolve the conflict. Due to an increase in chromosome length as a result of increasing the number of genes, in order to reduce the computational difficulties, they proposed a new model called Stochastic Varying Chromosome Length Genetic Algorithm with water Quality constraints (SVLGAQ).

Subsequent to preceding studies, Shirangi and Kerachian (2007) attempted to minimize both the computational difficulties and run-time problems by applying simplifying assumptions. They simulated the quality of Iran's 15-Khordad dam reservoir using the one-dimensional models. As different stakeholders were involved in the reservoir operation, the Young Conflict Resolution Theory was also utilized by Shirangi et al. (2008) to resolve the existing conflict of interests; this model was not effective in cases when more than two decision makers were involved in the so-called optimizing operating

procedure. Shirangi et al. (2016) developed the Cooperative Conflict Resolution Theory. In their study, they used the Bayesian networks as a novel type of learning model to develop real-time operating rules. Soltani et al. (2010) combined an ANFIS-based simulation and a genetic algorithm to speed up the calculation of policies and regulations for qualitative and quantitative operation of reservoirs system. They used a Nash multiplicative utility function with flexibility in supplying the downstream water, reservoir storage volume, and water quality. Mojarabi-kermani et al. (2018) developed a new model based on Fuzzy Set Theory to determine priorities in decision-makers' strategies of optimal qualitative-quantitative operation management of dam reservoir. Mojarabi-kermani et al. (2019) developed the new method for optimum and real time quantitative and qualitative operation of the reservoirs based on fuzzy logic with focusing on group conflict resolution, consequently as a step towards the development of previous models.

In their study, the best exploitation scenario was not determined. There have been valuable studies which have attempted to investigate the use of Game Theory in quantitative and qualitative utilization of dam's reservoirs, but many questions remained unanswered. To what extent does the decision-makers' bargaining power originated in politics or economy, etc., affect the outcome of the negotiations? How can we evaluate the effect of the presence of decision makers with the limited power on the negotiations? Given that decision makers have the different strategies, how can we determine the prioritization of using each strategy for each decision maker versus the strategies of other players? How can we define the different game scenarios based on the decision makers'

strategies? How can we set the best exploitation scenario derived from its strategies and priorities?

In this paper, a new method is proposed for conflict resolution under uncertainty through the optimization of quantitative and qualitative operation of dam's reservoir system. For this purpose, an efficient trade-off curve developed by Mojarabi-kermani et al. (2019) is used. This trade-off obtained by an algorithm combining a multi-objective genetic algorithm (GA)-based optimization model and a one-dimensional water quality simulation model (WQRRS) is merely the output of a mathematical model and practically does not satisfy the stakeholders' utilities. Thereafter, using the concept of the fuzzy game, for the first time, the utilities of the decision makers involved in a conflict resolution problem in water resources management are analyzed.

According to the proposed method, the players determine their strategies regarding both fuzzy and crisps behaviors, while, from each player's point of view, in turn the strategies have their own fuzzy and crisps priorities. Ultimately, based on the concept of Nash equilibrium, an agreement interval is proposed as an optimized solution instead of a crisp one for N-players. In this study, the 15-Khordad Dam of Iran is considered as a case study with some qualitative shortcomings due to a diversity of stakeholders' utilities. By means of the above-mentioned method, regarding the existing uncertainties, an agreement interval is obtained for conflict resolution problem. The main purpose of this study is to provide a fuzzy conflict resolution method for quantitative and qualitative operation of dam's reservoir system and mobilize many decision makers with a variety of utilities and priorities so as to attend at the bargaining table.

The most outstanding novelties of this paper contribution are as follows:

- a) Under bilateral negotiation conditions for the dam reservoir quality and quantity operation, decision-makers often face two major options. The first option for each decision maker is the possibility of an independent and non-cooperative presence in the negotiation, and the second option for each decision maker is the likelihood of forming a coalition with other decision makers with the same utility, in which case, one seeks to increase his own contribution to the reservoir operation via participating in a cooperative bargaining game and increasing the level of bargaining power. In this paper, for the first time, in a two-player game, these two major options are considered as decision-makers' strategies.
- b) In this paper, for the first time, in a bilateral negotiation, the priority value of using each strategy for each decision maker versus the rival's selective strategies is determined by presenting a fuzzy prioritization matrix for each decision maker.
- c) In this paper, for the proposed method, different game-based scenarios are defined according to the decision makers' strategies.
- d) In this paper, for the first time, a probability matrix is calculated for different game-based scenarios in the proposed method, and using the Nash equilibrium, the best scenario and the best combination of strategy for each decision-maker in negotiating with a competitor are obtained.

2 Materials and Methods

To promote the previous studies on dam reservoirs quality simulation, a methodology based on the Game Theory and fuzzy sets focusing on Mamdani method consisted of three main steps of fuzzification, inference, and defuzzification was used in this study.

The structure of the proposed model involved a high potential and flexible method based on the fuzzy logic to consider the natural uncertainties in the complex decision-making problems.

Taking the approach presented by Garagic and Cruz (2003) into account, a model with some innovations was developed to determine the strategies, priorities, and scenarios, and fuzzificate the strategies and priorities based on three main factors of total dissolved solids (TDS), water supply, and utilities to calculate the priority matrix for different combination of strategies. Considering the concept of fuzzy logic, a set of linguistic functions was determined for each player based on his vision to evaluate each possible accident occurring in the game space. Furthermore, a new method for calculating the priority matrix elements was proposed by overlapping the fuzzy strategy diagrams of all players for the same scenario. Figuring out the intersection points, the corresponding priority was evaluated for each player in the combination of strategies as a matrix element.

Moreover, considering decision makers' bargaining power, two major players and two minor ones were chosen in the game space. Thus, when the strategies of the major players were determined, the utilities of the minor players were indirectly considered in the game space. In most of the cases of complex conflict resolution and decision-making problem, the stakeholders who had a lower bargaining power were usually ignored in order to simplify the game space. However, according to the proposed fuzzy based model, the utility of such organs could be effective and had a profound influence on the pay-offs.

In the fuzzy game, let P be a set of players and C be the number of the constraints of the fuzzy game. If X introduces the feasible strategies in the decision space and U introduces the priority of players from each feasible strategy, the range of feasible strategies and priorities is represented by two sets of linguistic terms $L(X)$ and $L(U)$. In fact, the fuzzy aspect of the strategies and priorities is represented by these two linguistic terms.

In order to analyze the three steps of fuzzification, inference, and defuzzification, the following operators are defined:

μ : The fuzzy membership function which fuzzificates the process

g : Inference of the fuzzy information

δ : Turn the fuzzy information to a crisp number

The membership function μ assigns a number between 0 and 1 to the strategies of the players in a set of function $T(X, L)$ which shows the duplicate behavior of fuzzy and crisps for each strategy to fuzzificate it:

$$\mu_{T(X,L)}(X) : X \rightarrow [0,1] \quad (1)$$

In the inference step, operator g assigns a priority of the set of U to each strategy belonging to the set of X via function F as follows:

$$g : F(X) \rightarrow F(U) \quad (2)$$

In a fuzzy game, the relation between the strategies can be presented as the rules of the game. For example, for a two-player game, $X^1 \in X_A$ and $X^2 \in X_B$ illustrate a set of the strategies for the first (A) and second (B) players, respectively. A set of priorities for the players A and B are given as $U^1 \in U_A$ and $U^2 \in U_B$. The rule base for these two players which defines the relation between the strategies and priorities for each player is elaborated as below:

$$\begin{aligned} \text{Rule1: } & \text{If } [X^i \in T(A) \text{ AND } X^j \in T(B)] \\ & \text{then } [U^k \in T(U_A)] \end{aligned} \quad (3)$$

$$\begin{aligned} \text{Rule2: } & \text{If } [X^i \in T(A) \text{ AND } X^j \in T(B)] \\ & \text{then } [U^k \in T(U_B)] \end{aligned} \quad (4)$$

Using these rules and the membership functions, inference of the fuzzy information can be performed as follows:

$$\begin{aligned} \mu_{\Gamma}^A(X^i, X^j, U^k) &= \text{Min}(\mu_{T(A)}(X^i), \mu_{T(B)}(X^j)) \cdot \mu_{T(U_A)}(U^k) \\ &= \mu_{P(i,j,k)}^A \cdot \mu_{T(U_A)}(U^k) \end{aligned} \quad (5)$$

$$\begin{aligned} \mu_{\Gamma}^B(X^i, X^j, U^k) &= \text{Min}(\mu_{T(A)}(X^i), \mu_{T(B)}(X^j)) \cdot \mu_{T(U_B)}^2(U^k) \\ &= \mu_{P(i,j,k)}^B \cdot \mu_{T(U_B)}(U^k) \end{aligned} \quad (6)$$

Where Γ is a fuzzy subset of the Cartesian product $X \times U$. The defuzzification step is obtained by a priority function mapping $F(U)$ to a set of the players' priorities U as follows:

$$\delta_S : F(U) \rightarrow U \quad (7)$$

In this step, using the Mamdani method of the center of gravity (COG) and based on the selected scenarios from each player's viewpoint, some crisp numbers are obtained so as to show the possibility of choosing a feasible strategy according to the rival's priorities.

$$J^A = \sum_{i,j,k} \mu_{T(U_A(U^k))} \cdot \mu_{P(i,j,k)}^A / \sum_{i,j,k} \mu_{P(i,j,k)}^A, \quad \sum_{i,j,k} \mu_{P(i,j,k)}^A \neq 0 \quad (8)$$

$$J^B = \sum_{i,j,k} \mu_{T(U_B(U^k))} \cdot \mu_{P(i,j,k)}^B / \sum_{i,j,k} \mu_{P(i,j,k)}^B, \quad \sum_{i,j,k} \mu_{P(i,j,k)}^B \neq 0 \quad (9)$$

It is obvious that these crisp numbers are not the same for different players due to their different priorities. However, for each player, a priority matrix is formed that its rows and columns are equal to the number of strategies for each player, and the matrix elements represent the possibility of using different combinations of strategies from all players' perspectives. The superposition of these two matrices yields a new matrix with its elements as an ordered pair. Accordingly, the new matrix can be used to obtain the Nash equilibrium point.

In the following sections, the efficiency of the method is examined via analyzing the case study results.

2.1 Case study

To determine the efficiency of the above-mentioned models in quality and quantity optimization of operation of reservoir operation, the 15-Khordad Dam was evaluated for

analysis. It is one of the ten largest dams in Iran with salinity problems. The 15- Khordad Dam with 54 meters elevation above the riverbed is located at the upstream of Qomroud river basin in the central part of Iran in the vicinity of Delijan and Mahallat towns. The stream network of Qomroud River Basin is shown in figure 1. The dam is used to capture the runoff from the Qomroud watershed for agricultural irrigation use of more than 8,000 hectares, water supply to the city of Qom, as well as for flood and sediment control. “Salinity” or “total dissolved solids” (TDS) are the most important problems of this dam, having led to the growth of the electrical conductivity (EC) of the dam from 1000 μ mhos /cm to 4000 μ mhos /cm in a 5- year time interval . Namely increasing EC is affected by factors such as, consecutive years of drought, thermal and salinity stratification, improper operation, intense evaporation from the lake, poor quality of the geological structure of the reservoir, and poor quality water (particularly because of the release and the pass-through of the water of Shoor and Darbandeshoor Rivers to the dam). Hence, the operational management of the dam is very important due to both its quality and the interest of the beneficiary players.

2.2 Simulation Model

Shirangi et al. (2008) simulated the quality of Iran's 15-Khordad dam reservoir using the one-dimensional models. They edited the text file of Water Quality for River-Reservoir Systems (WQRRS) model and integrated it with Genetic Algorithm (GA) to determine the optimal quantitative-qualitative utilization of each value per month and set it for a long-term horizon. The basic assumption of this model was its similarity to HEC-5Q (USACE 1986) model. The reservoir was simulated as a one-dimensional case with horizontal layers of defined volume, surface, and thickness. Each layer was assumed to

be perfectly homogeneous and mixed. Indeed, the temperature and density of each layer in any horizontal volume element was exactly the same. The diffusion and transition between layers were specified through physical conditions of the system such as entry and exit points of flow. In this paper the above model is used to simulate the quality of Iran's 15-Khordad dam reservoir.

2.3 Stakeholders

Identifying the organizations with an active interest in the operation of the 15- Khordad dam is the first step in the assessment of stakeholder's situation. The two major stakeholders that represent various organizations and sub-divisions are the Ministry of Agriculture (Ag) and Urban Water Organization (Ur). Furthermore, there are two other stakeholders, including Ministry of Industry (Mi) and Environmental Organization (Eo), with the less sensitivity to the quantity of the water; however, To Environmental Organization, the quality of water matters as a vital issue.

The identification of stakeholder interests is one of the most crucial aspects of an assessment. Ag allocates a very large amount of water to irrigation and agricultural land. According to the policy of this organization, the quantity of water is more significant than its quality, while Ur has to accentuate the quality of the water for urban water supply as well as its quantity. On the other hand, since the water demand for the minor players, Mi and Eo, is lower than the major stakeholders, Ag and Ur, the bargaining power of these organizations is also lower than that of the major stakeholders. Taking part in a coalition with the major players is the best policy for minor stakeholders to gain a better pay off

and apply its water policies quantitatively. Thus, the space of the game belongs to Ag and Ur as the main players, while Mi and Eo are considered as minor players.

2.4 Data collection

The data of 15- Khordad dam for a 30-year time interval were collected by Mojarabikermani et al. (2019). The purported research obtained an optimized quality and quantity trade-off curve using a combination of the reservoir's quality simulation model and GA optimization model which illustrated the relation between the lack of water supply and the TDS (Figure 2). Then, two utility diagrams were set based on the trade-off and consulting with the representatives of both the Ag and Ur (Figures 3 and 4). Using the above mentioned trade-off, TDS was considered as the main water quality index. Therefore, the trade-off curve displays that the quantity decreases as the quality improves. Evidently, as the water quality improves, the water supply decreases, and for a large amount of water supply, the expected quality is not achieved and TDS increases.

3 Results and Discussion

The main purpose of this paper is to analyze the conflict resolution problem in the dam reservoir based on the proposed fuzzy model as illustrated in Figure 5.

3.1 Problem description

A conflict resolution for the two main decision makers was introduced in the previous section on the issue of water sharing of the 15-Khordad Dam. The major players set (P) and the minor players set were defined as (C), $P = \{Ag, Ur\}$, $C = \{Mi, Eo\}$, respectively. It is assumed that the first need and right of water for Ag, Ur, Mi, and Eo are supplied, and the problem is sharing the water surplus.

Since the quantity of water is a priority for Ag and in contrast Ur considers the quality, the question raises how much water and with what TDS index can be allocated to each player. Moreover, each of these major players can achieve a coalition with one of the minor players of Mi or Eo to bargain for an additional share. Apparently, it is not favorable for Mi, with a quantity-oriented point of view, and Eo with a quality point of view, to attend at the bargaining negotiations independently because they may receive less water, while in the case of coalition with one of the major players, they could enjoy more advantages. This is a favorite situation for Mi and Eo as it increases their bargaining power.

Accordingly, the two main decision makers might probably determine the feasible strategies based on their priorities as follows:

- A. Bargaining of Ag versus Ur,
- B. Bargaining of Ag versus a coalition of Ur, Mi, and Eo,
- C. Bargaining of Ag versus a coalition of Ur and Mi,
- D. Bargaining of Ag versus a coalition of Ur and Eo,
- E. Bargaining of a coalition of Ag and Mi versus a coalition of Ur and Eo,
- F. Bargaining of Ur versus a coalition of Ag, Mi, and Eo,
- G. Bargaining of Ur versus a coalition of Ag and Mi,
- H. Bargaining of Ur versus a coalition of Ag and Eo,

Since both players of Ag and Mi consider the quantity of water supply, none can take part in a coalition with Ur; therefore, the strategies B and C are impossible. Besides, the strategies of F and H are also unattainable because of Ur and Eo are both quality-oriented

and cannot achieve a coalition with Ag. It is noteworthy that in both cases of E and G, Ag participates in a coalition, no matter Ur plays individually or within a group. This occurs in the same way for the cases of D and E in which Ur participates in a coalition. However, there is only one group strategy for each major player. Thus, the possible logical strategies for each major player are limited to the following: Ag has two options of A or group (E or G) defined as Ag_{S1} and Ag_{S2} , respectively, and the only options for Ur are the cases A and group (D or E) defined as Ur_{S1} and Ur_{S2} , respectively. Therefore, the strategy sets are determined as:

$$X_1 = \{Ag_{S1}, Ag_{S2}\}, X_2 = \{Ur_{S1}, Ur_{S2}\}$$

Let U be the values associated with the players' priorities: $U = \{0.25, 0.5, 0.75, 1.00\}$. Fuzzification of the strategies (X) and the priorities (U) are represented by a set of linguistic terms defined as:

$$L(X) = \{\text{Strong, Medium, Weak}\}$$

$$L(U) = \{\text{Strong, Strong-Medium, Medium, Medium-Weak, Weak}\}$$

3.2 Fuzzification and prioritizing the possible strategies in the fuzzy realm

According to the trade-off curve in Figure 2 and the utility diagrams of Ag and Ur in Figures 3 and 4, the fuzzy membership functions for each strategy of both major players are exhibited in Figures 6-9. Furthermore, the priority and utility values along with the water supply and TDS ranges for Ag and Ur are shown in Tables 1, 2, 3, and 4. For example, the first row in Table 1 shows that for the first strategy of Ag (Ag_{S1}) and TDS

interval of 1000-1300, the water quality is relatively acceptable, whereas the water supply does not fulfill their requirements, ergo this region is weak with the priority value of 0.25. Conversely, based on the last row of this table, for the TDS range of 1500-2000, the water quality is too low; however, the water supply satisfies Ag needs. Hence, this region is strong with the priority value of 1 for Ag that has a quantity-oriented opinion. It can be inferred that, not assuming the quality of water, the strong region of a strategy for Ag is where the water supply is larger. Thus, the medium and weak regions of Ag strategies can be detected. This is in the opposite direction of Ur policy with a quality-oriented opinion.

Mi considers water quantity more than water quality, and although the water share of Mi as a minor player is much less than Ag and its bargaining power is much weaker, the policy of Ag as a major player in the coalition is to satisfy the water needs of Mi, shifting the second strategy of Ag (Ag_{S2}) to the right in comparison with Ag_{S1} (Figure 7). This occurs for the second strategy of Ur (Ur_{S2}) since Eo as a minor player is quality-oriented; in addition, its policy is more quantitative than Ur; therefore, Ur_{S2} shifts slightly toward lower TDS with higher quantity (Figure 9). However, these shifts in both cases of Ag_{S2} and Ur_{S2} do not significantly affect the general policies of the major players.

3.3 Priority matrix

Inference of the fuzzy data is performed using a matrix called priority matrix. This matrix determines each player's priorities based on all players' strategies in different conditions. For instance, Figure 10 shows the Ur's priority intervals for its second strategy with the linguistic values of (a: Strong), (b: Strong-Medium), (c: Medium-Weak), and (d: Weak).

One can assign the priority values of 1.00, 0.75, 0.50 and 0.25 to the intervals of a, b, c, and d, respectively, and the priority values for the intersection points of G, E, and F are set as the average values of the adjacent areas. It should be noted that the length of the intervals does not necessarily need to be equal, and a small interval may have higher priority and vice versa. The same process is repeated for the first strategy of Ur and for both strategies of Ag based on its quantity-oriented policy. In the next step, through overlapping the possible players' strategy compositions and finding the intersection points with their priority values based on the players' opinions, it is possible to obtain the priority matrix.

In our case study, four different compositions of strategies are detected, and their fuzzy diagrams are illustrated in Figures 11, 12, 13, and 14, and the fuzzy priority matrixes of the players are defined in Tables 5 and 6.

Table 5 shows different priorities from the point of view of Ag in bargaining with Ur. According to table 5, for example, if Ag applies second strategy in the strong area and Ur uses the second strategy in the weak area, such situation from the point of view of Ag with the priority value 0.875 is 87.5 %. Similarly, priorities can be predicted from the point of view of Ur in various bargaining situations, as shown in Table 6. For example, if Ag uses the second strategy in the weak area under negotiation conditions, the priority value for Ur when using the first strategy in medium area is equal to 0.375 or 37.5%. Therefore, as shown in Tables 5-6, the priorities can be predicted from the viewpoint of each of Ags and Urs in various bargaining situations. A problem that exists in most of cases of bargaining as a barrier is that decision-makers do not have clear and precise

understanding of what they demand. The advantage of the proposed method is that each the decision maker in the bargaining situation knows the value of the priority of his chosen strategy against rival's different strategy, therefore, they will resume to bargain with a better understanding of the various situations, and in fact, the likelihood of reaching an agreement increases. In the remainder of this paper, different scenarios for the presence of decision makers in the bargaining are presented, and Nash equilibrium point is determined; accordingly, it specifies that each decision maker adopts the very strategy as the best response to the rival's strategy, though the resulting profit might not be quite ideal.

3.4 Scenarios in a fuzzy environment

Using the expert consultants, for each possible and logical combination of strategies, one can set a scenario with a percentage of utility which is the representative of the utility interval of a stakeholder.

First scenario: Both players in a non-coalition case prefer to play with their first priority, but since the bargaining power of the Ag is stronger than Ur, it is impossible for Ur to do so. Thus, the first scenario is as follow: the utility value of Ag in the strong area of Ag_{S1} with the priority value 1 is 70%, and the utility value of Ur in the medium-strong area of Ur_{S1} with the priority value 0.75 is also 70%.

Second scenario: Although the utility value of Ur in coalition with Eo decreases in comparison with the non-coalition case, the quantity of its water share increases. Therefore, the second scenario is as follows: the utility value of Ag in the strong area of

Ag_{S1} with the priority value 1 is 70%, and the utility value of Ur in the medium-weak area of Ur_{S2} with the priority value 0.5 is 50%.

Third scenario: The bargaining power of Ag in coalition with Mi is stronger than the non-coalition case, consequently to encourage Ur, Ag should not play a part with its first priority; otherwise, no agreement is reached. As a result, the third scenario is as follows: the utility value of Ag in the medium-strong area of Ag_{S2} with the priority value 0.75 is 80%, and the utility value of Ur in the medium-strong area of Ur_{S1} with the priority value 0.75 is 70%.

Fourth scenario: If both of the major players participate in the appropriate coalition, the values of their priorities are influenced by the utility of their cooperators. Thus, the forth scenario is as follows: the utility value of Ag in the medium-strong area of Ag_{S2} with the priority value 0.75 is 80%, and the utility value of Ur in the medium-weak area of Ur_{S2} with the priority value 0.5 is 50%.

In the defuzzification step, for each of the determined scenarios and from each player's point of view, a crisp number will be produced into a matrix called payoff matrix of the player. By superimposing the two payoff matrixes of the two stakeholders, a bi-matrix with the matrix elements as an ordered pair will be obtained. This bi-matrix is used to determine the best scenario and the best strategy combination via Nash equilibrium concept. These steps should be performed for all scenarios in the same way. Here, the details of the first scenario are described in the following section and the results from other ones are presented as well.

Scenario1: according to the first scenario, Ag demands to play a role in the strong area of Ag_{S1} , and Ur has to participate in the medium-strong area of Ur_{S1} . Thus, two strategy combinations with the players' priority and utility are reached:

1. Strong-strong: $\{(Ag_{S1}, \text{strong}, 1, 70\%), (Ur_{S1}, \text{strong}, 0.75, 70\%)\}$
2. Strong-medium: $\{(Ag_{S1}, \text{strong}, 1, 70\%), (Ur_{S1}, \text{medium}, 0.75, 70\%)\}$

Using the intersection point of the utility diagram with the Trade-off Curve, the corresponding TDS is found, and then via the fuzzy diagrams of any strategies, the corresponding membership function (μ) of any TDS is obtained.

In the first strategy, there would be: $\mu(Ag \text{ strong}) = 1, \mu(Ur \text{ strong}) = 1, \mu(Ur \text{ medium}) = 0.5$

Now using Tables 5 and 6, the priority for each strategy combination is as follows:

Priority strong – medium (Ag) = 0.75 , *Priority strong – medium* (Ur) = 0.25

Priority strong – strong (Ag) = 0.0 , *Priority strong – strong* (Ur) = 0.0

Now introducing J_i as:

$$J_1 = \min(\mu(Ag), \mu(Ur)) \times \text{Priority of a player}$$

Ag point of view in strong-medium case: $J_1 = \min(1, 0.5) \times 0.75 = 0.5 \times 0.75$

Ag point of view in strong-strong case: $J_2 = \min(1, 0.5) \times 0.00 = 0.5 \times 0.00$

Using J_i , a crisp number for the pay-off matrix element can be yielded via finding the center of gravity as follows:

$$J_{a,b} = \frac{\sum J_i}{\sum \mu_i^{min}}$$

$$J_{11}^{Ag} = \frac{0.5 \times 0.75 + 0.5 \times 0.0}{0.5 + 0.5} = 0.375$$

$$J_{11}^{Ur} = \frac{0.5 \times 0.25 + 0.5 \times 0.0}{0.5 + 0.5} = 0.125$$

In this way, the two pay-off matrixes are obtained as follows:

$$J_{Ag} = \begin{bmatrix} 0.375 & 0.303 \\ 0.96 & 0.724 \end{bmatrix}$$

$$J_{Ur} = \begin{bmatrix} 0.125 & 0.250 \\ 0.460 & 0.448 \end{bmatrix}$$

3.5 Nash equilibrium

By superimposing the two payoff matrixes J_{Ag} and J_{Ur} , a bi-matrix with its elements as an ordered pair will be determined, and then Nash equilibrium can be applied to it; the description of its elements is shown in Table 7.

Analyzing the bio-matrix, one can conclude that, for the Ur_{S1} , Ag has to choose its first strategy (Ag_{S1}), and if Ur chooses its second strategy (Ur_{S2}), Ag would choose its first strategy Ag_{S1} . However, for Ag_{S1} , Ur will respond to its second strategy Ur_{S2} , and if the

second strategy of Ag is chosen (Ag_{S2}), Ur has to respond to its second strategy (Ur_{S2}). Therefore, the best combination is (Ag_{S1} , Ur_{S2}) in order to gain the best possible payoffs. This combination is known as Nash equilibrium.

Finally, considering the best combination of possible strategies and their priorities, the TDS intervals for each player are detected according to their fuzzy diagrams (Table 8).

It is clear that the overlap of TDS interval is [1500, 1650], which is an agreement interval. Moreover, both the percentage of water supply and utility intervals of Ag and Ur can be obtained according to the agreement interval. Although it merits mention that Nash equilibrium is not an ideal solution for the stakeholders, it is the best response of each decision maker against the rivals' strategies on the bargaining table. Indeed, Nash equilibrium yields the best value for water supply both qualitatively and quantitatively resulting from the group negotiations. Furthermore, it is possible to repeat the calculation for the agreed TDS to optimize the average quantity of monthly water supply for a 30-year time horizon.

4 Conclusion

In this study, a new decision-making method was proposed for conflict resolution regarding the quantitative and qualitative limits of water allocation under the uncertain conditions in dam reservoir operation. The main reason of presenting this method is to develop a model which can consider the minor decision makers' perspectives along with the major ones and their effects on the payoffs. Since the data and strategies of the decision makers are inherently uncertain, the proposed methodology is able to reflect

these uncertainties based on the fuzzy logic which can be a more efficient solution than the binary logic.

In the proposed methodology, given the conditions and uncertainties available, the ground has been provided for all decision-makers to determine the best possible strategies so that they can bring the most benefit to them on the negotiation table. This amount of profit, although maximized, may not necessarily be ideal for any decision maker due to the presence of different decision makers with different and occasionally conflicting appeals and strategies, but it is agreed upon by all. One of the benefits of the proposed method is thus the possibility of modeling negotiations with a large number of decision makers with different strengths and strategies, so that there would be the best combination of strategies for all decision makers leading to the most possible profit for them. Furthermore, each decision maker knows to use which strategy against other decision makers' strategies to maximize its share in the negotiation, even though this share may not be ideal. Analyses demonstrate that in a case study (15 Khordad Dam), after determining the utility and strategies of the agricultural and urban water organization in quantitative and qualitative operation of the reservoir of the dam as well as determining its prioritization matrix using mathematics with fuzzy logic, the agriculture sector selects the first strategy (participation in the game without any urges to participate in the coalition) whereas the Urban Water Organization selects the second strategy (participation in the game by the coalition with the environmental sector). The application of the model portrays that, when the decision makers opt for this strategy combination, the approved range for the TDS value is between 1500 and 1650 mg/l

according to their utility and preferences. Providing this range for the TDS value is another advantage of the proposed approach compared to the previous studies, since in addition to increasing the speed of decision making, it can also boost the flexibility of the decision maker in realizing the value of the TDS. Using this framework, disputes between decision-makers are sharply reduced and it paved the way for modeling the negotiation. The most significant accomplishments of this research are:

- a) In the proposed methodology, for each decision maker, the priority to choose any strategy can be determined against other decision makers' choices.
- b) Using the proposed method and in a fuzzy logic multiplayer game, Taking the decision makers' preferences and interests into account, prior to the onset of the negotiation, all decision makers can determine the best strategy for their most possible contribution to them depending on the negotiation conditions.

To determine the effect of different economic, social, and political criteria, decision-makers would find decision-making models according to the results of the current research practically beneficial.

Acknowledgments The technical contribution made by Prof. Reza Kerachian is hereby acknowledged.

Declarations

Funding The authors did not receive support from any organization for the submitted work.

Conflicts of interest/Competing interests None.

Availability of data and material All of the required data have been presented in our article.

Code availability All written codes are ready to be sent.

Authors' contributions Alborz Mahmoudi: Research, Writing and Revising.

Ehsan Shirangi: Supervising and Editing.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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Table 1 Regions, TDS, Utilities, Water Supplies, and priorities for first strategy of Ministry of Agriculture.

Region	TDS (mg/L)	Utility	Water Supply	Priority
Weak	1000-1300	0%-10%	0%-25%	0.25
Weak-Medium	1300-1400	10%-45%	25%-50%	0.50
Medium-Strong	1400-1500	45%-60%	50%-60%	0.75
Strong	1500-2000	60%-100%	60%-100%	1.00

Table 2 Regions, TDS, Utilities, Water Supplies, and priorities for second strategy of Ministry of Agriculture.

Region	TDS (mg/L)	Utility	Water Supply	Priority
Weak	1000-1400	0%-45%	0%-50%	0.25
Weak-Medium	1400-1550	45%-70%	50%-70%	0.50
Medium-Strong	1550-1700	70%-90%	70%-90%	0.75
Strong	1700-2000	90%-100%	90%-100%	1.00

Table 3 Regions, TDS, Utilities, Water Supplies, and priorities for first strategy of Urban Water Organization.

Region	TDS (mg/L)	Utility	Water Supply	Priority
Strong	1000-1200	80%-100%	0%-20%	1
Strong-Medium	1200-1400	65%-80%	20%-50%	0.75
Medium-Weak	1400-1600	50%-65%	50%-80%	0.50
Weak	1600-2000	20%-50%	80%-100%	0.25

Table 4 Regions, TDS, Utilities, Water Supplies, and priorities for second strategy of Urban Water Organization.

Region	TDS (mg/L)	Utility	Water Supply	Priority
Strong	1000-1350	75%-100%	0%-42%	1
Strong-Medium	1350-1500	60%-75%	42%-65%	0.75
Medium-Weak	1500-1650	45%-60%	65%-85%	0.50
Weak	1650-2000	20%-45%	85%-100%	0.25

Table 5 The Priority Matrix (Perspective of Ministry of Agriculture).

The Strategies of Ministry of Agriculture								
			Ag_{s1}			Ag_{s2}		
			W	M	S	W	M	S
Strategies of Urban Water Organization	Ur_{s1}	W	0.00	0.75	1.00	0.50	0.75	0.875
		M	0.50	0.625	0.75	0.375	0.50	0.750
		S	0.25	0.50	0.00	0.25	0.00	0.000
	Ur_{s2}	W	0.00	0.00	1.000	0.50	0.75	0.875
		M	0.50	0.75	0.875	0.50	0.50	0.750
		S	0.375	0.50	0.500	0.375	0.50	0.000

Table 6 The Priority Matrix (Perspective of Urban Water Organization).

The Strategies of Ministry of Agriculture								
			Ag_{s1}			Ag_{s2}		
			W	M	S	W	M	S
Strategies of Urban Water Organization	Ur_{s1}	W	0.00	0.50	0.375	0.50	0.50	0.25
		M	0.75	0.625	0.25	0.375	0.50	0.50
		S	0.875	0.75	0.00	0.875	0.00	0.00
	Ur_{s2}	W	0.00	0.00	0.375	0.50	0.75	0.875
		M	0.75	0.50	0.625	0.75	0.50	0.500
		S	1.00	0.75	0.750	0.875	0.75	0.000

Table 7 Bi-Matrix.

Iran Ministry of Agriculture			
		Ag_{S1}	Ag_{S2}
Urban Water Organization	Ur_{S1}	(0.125, 0.375)	(0.25, 0.303)
	Ur_{S2}	(0.46*, 0.96*)	(0.448, 0.724)

Table 8 The Best Combination of Possible Strategies.

	TDS interval	Priority
Ag_{S1}	[1500, 2000]	1
Ur_{S2}	[1500, 1650]	0.5