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Developing a comprehensive model of the optimal exploitation of dam reservoir by combining a fuzzy-logic based decision-making approach and the young's bilateral bargaining model

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Abstract. Given the limited water resources and the presence of multiple decision makers with different and usually conflicting objectives in the exploitation of water resources systems, especially dam's reservoirs; therefore, the decision to determine the optimal allocation of reservoir water among decision-makers and stakeholders is a difficult task. In this study, by combining a fuzzy VIKOR technique or fuzzy multi-criteria decision making (FMCDM) and the Young's bilateral bargaining model, a new method was developed to determine the optimal quantitative and qualitative water allocation of dam's reservoir water with the aim of increasing the utility of decision makers and stakeholders and reducing the conflicts among them. In this study, by identifying the stakeholders involved in the exploitation of the dam reservoir and determining their utility, the optimal points on trade-off curve with quantitative and qualitative objectives presented by Mojarabi *et al.* (2019) were ranked based on the quantitative and qualitative criteria, and economic, social and environmental factors using the fuzzy VIKOR technique. In the proposed method, the weights of the criteria were determined by each decision maker using the entropy method. The results of a fuzzy decision-making method demonstrated that the Young's bilateral bargaining model was developed to determine the point agreed between the decisions makers on the trade-off curve. In the proposed method, (a) the opinions of decision makers and stakeholders were considered according to different criteria in the exploitation of the dam reservoir, (b) because the decision makers considered the different factors in addition to quantitative and qualitative criteria, they were willing to participate in bargaining and reconsider their ideals, (c) due to the use of a fuzzy-logic based decision-making approach and considering different criteria, the utility of all decision makers was close to each other and the scope of bargaining became smaller, leading to an increase in the possibility of reaching an agreement in a shorter time period using game theory and (d) all qualitative judgments without considering explicitness of the decision makers were applied to the model using the fuzzy logic. The results of using the proposed method for the optimal exploitation of Iran's 15-Khordad dam reservoir over a 30-year period (1968-1997) showed the possibility of the agreement on the water allocation of the monthly total dissolved solids (TDS)=1,490 mg/L considering the different factors based on the opinions of decision makers and reducing conflicts among them.
Keywords: bargaining model; fuzzy decision making; reservoir exploitation; water quality

1. Introduction

Due to both the lack of high-quality water resources and their high economic value, the exploitation of water resources systems, especially dam's reservoirs, in countries like Iran, suffering from water scarcity, is of particular importance. The reservoirs operation plays an increasingly important role in coping with the serious water, food and energy crisis (Niu *et al*. 2021). Also, due to the presence of multiple decision makers with different utilities and usually conflicting objectives in the exploitation of water resources systems, the application of the fuzzy multi-criteria decision-making (FMCDM) methods and game theory (GT) to reduce conflicts among managers and increasing their ability to determine the reservoir exploitation policies can be very attractive. Bin *et al*. (2019), based on the thought of multi-index fusion, fuzzy matter-element model evaluating water source behavior was constructed by matter-element transform. This model can process the comprehensively hydrogeological data, ecological environment, water pollution, surface disturbance, etc. Xu *et al*. (2021) optimized reservoir operations for trade-offs considered between the economic objectives and legacy phosphorus management. Khorsandi *et al*. (2022) developed multi-Objective firefly integration with the K-nearest neighbor to decrease simulation model calls in order to hasten the occurrence of the multi-objective optimization reservoir operation. Babamiri and marofi (2021) used non-dominated sorting genetic algorithm-II (NSGA-II) algorithm to optimize surface water resource systems with respect to quantity and quality simultaneously. Recently, Babamiri *et al*. (2022) presented an integrated fuzzy optimization-simulation approach of optimal operation of reservoir-river systems in terms of quantity and quality simultaneously.

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Abbasi *et al*. (2022) developed a novel method for the simultaneous management of both quantity and quality of reservoir outflow. Darbandsari *et al*. (2020) developed conflict resolution framework including an agent-based model for the management of urban water resources. En-Nasyry *et al*. 2020) developed a new method remediated by the accidental river pollution. Zhang and Thorburn (2022) developed a deep surrogate model (DSM) with spatio-temporal awareness for the estimation of water quality variables. Mardani Najafabadi *et al*. (2022) presented an efficient framework to manage water supply and demand in accordance with the economic and environmental objectives of the basin. Nikoo *et al*. (2018) developed a multi-objective simulation–optimization method for designing cutoff walls and apron of diversion dams. Sedighkia *et al*. (2022) proposed a daily timescale ANFIS-based model for the simulation of the aggregated monthly long-term inflow applied for the Ross River reservoir in northern Queensland, Australia. Saadatpour *et al*. 2020) proposed two surrogate models coupled with the evolutionary algorithm in an adaptive-recursive framework to develop the surrogate-based multi objective optimization technique (SBMOOT). SBMOOT was employed to derive the optimal reservoir operating strategies and the set of nondominated optimal solutions to increase the outflow water quality of reservoirs and maximize both water supply and hydropower energy generation.

The main objective of the present study was to develop a method combining the FMCDM methods and game theory to determine the optimal qualitative-quantitative allocation of dam's reservoir water with the aim of reducing the conflicts among the decision-makers and stakeholders. Multi-criteria decision making (MCDM) methods are selective and are a good way to choose the best alternative from among a set of alternatives by considering several different criteria with different degrees of importance (weights). Previous studies showed that MCDM methods were used for the quantitative-qualitative operation of water resources systems, especially dam's reservoirs. Rousis *et al*. 2008) evaluated the performance of MCDMs for ranking the e-waste management systems and the results showed that the MCDMs had good performance. Peche and Rodríguez (2009) developed a new method based on fuzzy logic to perform the environmental impact assessment (EIA) of these activities and projects. Dursun *et al*. (2011) also used MCDM techniques for performing an analysis based on multi-level hierarchical structure and fuzzy logic for the assessment of health-care waste treatment alternatives. Malekmohammadi *et al*. (2011) employed ELECTRE-TRI method to rank the optimal solutions of Non-dominated Sorting Genetic Algorithm-II (NSGA-II) developed for multi-objective operation optimization of a cascade system of reservoirs. Shirangi *et al*. (2023) used the ELECTRE I multi-criteria fuzzy decision model and the RUBINSTEIN bilateral bargaining model, to determine the optimal amount of quantitative-qualitative allocation of dam reservoir water. Mosadeghi *et al*. (2012) reviewed the potential uncertainties in environmental management decision making procedures and explored how uncertainty analysis in the framework of MCDM can address some of these uncertainties. The use of other mathematical models and their results, which prove extremely valuable, can be observed in previous studies (Keshtegar *et al*. 2020 a, b, Kolahchi *et al*. 2020, 2021, Hajmohammad *et al*. 2018 a, b, Alfurjan *et al*. 2021 a, b).

In decision making process, the person makes a decision without considering the reaction, while in many interactions the decision can lead to the reaction of the other party and when both parties are aware of the effects of these interactions, it is called the game. This mutual awareness is the most important difference between game theory and MCDM methods. Unlike MCDM methods, the reaction of the other party in the decision-making situations is also considered in game theory. In the operation of water resources systems, there are different decision makers who have different utilities and this often creates conflicts among them. Managers and decision-makers who have strategic thinking skills can make accurate calculations of their abilities and decisions, and their competitor reactions to these decisions. Strategic thinking can be defined as a thinking process focusing on how to interact with other decision makers and anticipate the competitor's possible behavior in the face of their own choices. The main objective of game theory is to give an attitude to the parties entering the negotiations so that they can calculate the decisions of the other party using strategic thinking. Numerous studies have investigated the application of game theory to resolve conflicts among the decision makers involved in the operation of water resources systems. For example, Kerachian and Karamouz (2006, 2007) and Soltani *et al*. (2010) employed the Nash bargaining model to consider the utility of decision makers involved in the operation of water resources systems. Also, the bilateral bargaining model developed by Young (1993) was used to resolve conflicts between two stakeholder groups involved in water resources management (Kerachian and Shirangi 2008, Shirangi *et al*. 2008, Bazargan *et al*. 2009, Niksokhan *et al*. 2009). Kerachian *et al*. (2010) proposed the Rubinstein's bilateral bargaining model for groundwater resources management, and the dam reservoir exploitation. Recently, Zanjanian *et al*. 2022) developed a novel framework for water right conflict resolution considering actors' power and inter-organizational relationships analysis. To determine reservoir optimal operational rules in the case of sudden methyl tert-butyl ether (MTBE) pollution, a risk-based simulation–optimization model was developed by Vanda *et al*. (2022) in order to simultaneously minimize unsatisfied water demand, the risk of violations of water quality standards, and the reservoir recovery time. Also, Haghighat *et al*. (2021) provided multi-objective conflict resolution optimization model for reservoir's selective depth water withdrawal, considering water quality. Eyni *et al*. (2021) used the correlated equilibrium concept and a regret-based behavioral model for shared the quantity and quality management of water resources. Kheirkhah Hasanzadeh *et al*. (2020) presented a fuzzy equilibrium strategy for sustainable water quality management in river-9reservoir system. Abdi-Dehkordi *et al*. (2021) developed a new sustainability assessment framework for the integrated management of water resources systems using distributed zoning and system dynamics approaches. Soltani *et al*. 2008) presented stochastic multi-purpose reservoir operation planning by scenario optimization and differential evolutionary algorithm. Karimi *et al*. (2011) evaluated the effects of water transport projects on long term water supply in Zayandehrood basin using multi-period optimization analysis. Hati and Panda (2021) presented a mathematical procedure for optimum design of axially loaded pile structure based on concept of Pareto-optimal solution and game theory associated with Nash non-cooperative and cooperative solution.

Shirangi *et al*. (2007, 2008) simulated the quality of Iran's 15-Khordad dam reservoir by combining the one-dimensional WQRRS model and the genetic algorithm (GA)-based optimization model. In their proposed method, the one-dimensional WQRRS model was developed in the optimizing loops and determined the quality status of the output flow and water stored in the reservoir in accordance with exploitation policies for the different stakeholders. They presented the trade-off curve with quantitative and qualitative objectives and determined the quantity of monthly water withdrawal over a 30- year period (1968-1997) based on the water quality expected by the decision maker (the level of total dissolved solids (TDS). For the first time, they employed the Young's bilateral bargaining model considering the possible conflicts among system decision-makers and stakeholders to determine the optimal point on the trade-off curve. In the model proposed by Shirangi *et al*. 2008), only water quality and water quantity were considered for the dam reservoir operation and other important factors affecting the stakeholder's opinion were not considered, and this was one of the important limitations of the proposed model. Shirangi *et al*. (2016) developed new person group conflict resolution model.

Mojarabi-kermani *et al*. (2018, 2019) developed a new fuzzy method for the qualitative-quantitative operation of the dam reservoirs, especially in countries facing water shortages. They also developed a new method based on game theory to select the optimal decision made by the players. The proposed method can help the player to make the optimal decision against the decisions of opponents in the negotiation process, leading to the highest possible profit. The result of the study did not show the highest profit for decision makers, but led to the relative satisfaction among them. In this study, with the aim of expanding the model proposed by Mojarabi-kermani *et al*. (2019), a new method combining a fuzzy-logic based decision-making approach and the Young's bilateral bargaining model was developed to determine the optimal quantitative and qualitative water allocation of Iran's 15-Khordad dam reservoir with the aim of increasing the utility of decision makers and stakeholders and reducing the conflicts among them. In their study, for the first time, Shirangi *et al*. (2008) could control the water withdrawal from the dam reservoir, considering the water quality issues and the utilities of the beneficiaries. In the study, they only paid attention to both the quantitative and qualitative criteria. In the following, Mojarabi *et al*. (2018, 2019) developed a model proposed by Shirangi *et al*. 2008). First, by changing the objective function and fuzzifying it, they made it possible to make a more accurate decision, considering the utility of the decision makers. Then they presented a new method to resolve the conflicts that arise between the decision makers. In their proposed method, a fuzzy utility function was presented for each decision maker, considering the water quality of the reservoir, and accordingly, for the first time, it was possible for each decision maker to select the best strategy providing the maximum profit. All studies were emphasized only both the quantitative and qualitative criteria.

The main idea of this paper was the simultaneous use of a fuzzy-logic based decision-making approach and game theory to manage the dam reservoir operation. Accordingly, after conducting an interview with the experts, five key criteria involved in the dam reservoir operation were considered from their point of view. These criteria included the allocated water quantity, the allocated water quality, the economic benefits of water allocation, the social conditions and expectations of the region, and environmental problems. After calculating the weights of criteria using the entropy method, the optimal points on the trade-off curve with quantitative and qualitative objectives presented by Mojarabi-kermani *et al*. (2019) were ranked based on the opinion of each stakeholder using the fuzzy VIKOR technique. Regarding the dam reservoir operation where there were different decision makers with different utilities and usually conflicting objectives, the alternatives (each point on the trade-off curve) might be ranked differently based on the decision makers' opinions. For example, an alternative that had the highest rank based on a decision maker's opinion might not necessarily had the highest rank from another decision maker point of view, and this could lead to the conflicts between them. After the optimal points on the trade-off curve were ranked based on the stakeholders' opinions, the Young's bilateral bargaining model was used to resolve the conflicts and determine the optimal point of agreement. One of the features of the proposed method was that on the one hand the complexities related to the combination of the different models in the framework of a single optimization model were greatly reduced, on the other hand, it is proved that if different factors affecting water allocation were be considered by managers, they did not insist on their opinions in negotiation process and overlooked their ideal positions. The analysis results of the proposed method demonstrated that due to key factors affecting the dam reservoir operation from the point of view of stakeholders, their views were closer to each other, leading to increasing their motivation to participate in the negotiation and increasing the probability of agreement. The results of using the proposed method for the optimal exploitation of Iran's 15-Khordad dam reservoir over a 30-year period (1968-1997) showed the possibility of the agreement on the water allocation of the monthly total dissolved solids (TDS)=1,490 mg/L considering the different criteria based on the opinions of decision makers.

2. Methodology

2.1 Multiple criteria decision-making methods

The decision-making process is a scientific method to select the best feasible solution. Decision makers simultaneously consider more than one criterion in the decision-making process when choosing an alternative among several alternatives. The criteria are sometimes quantitative or qualitative. On the other hand, the criteria may be in alignment and sometimes they are not in alignment. Due to multiple criteria, decision making is a complex task and involves choosing an alternative among several feasible alternatives. Multiple criteria decision-making (MCDM) methods can be very useful for the decision makers. Also, the fuzzy multi decision-making (FMCDM) methods are very useful in situations where the criteria are vague, or when the criteria are qualitative. Decision making is a methodological framework that aims to select an optimal alternative among a finite set of alternatives. These alternatives are evaluated based on different points, including criteria, aspects, attributes, and objectives. Olson (2004) found that TOPSIS performed better than AHP for adapting a basic forecasting model. Opricovic (1998) presented the VIKOR method, in which the compromise solution was a justified solution that was close to the ideal solution. The VIKOR method is based on the particular measure of closeness to the ideal solution. Compromise means an agreement established by mutual concessions. Both TOPSIS and VIKOR as the compromise programming methods are based on an aggregating function, representing closeness of an alternative to the ideal solution. The difference between two methods is that to eliminate the units of criterion function, TOPSIS uses linear normalization, whereas VIKOR applies vector normalization. Rashidi *et al*. (2018) conducted a study on water engineering. They employed MCDM method to select sealing element for earth dams. Using the VIKOR, they ranked the types of alternatives for the selection of sealing element for the Qasr-e-Shirin reservoir dam in Iran. A private Iranian company constructed this dam in Iran and the results of the study were technically and economically significant. The results were satisfactory. Zadeh (1962) proposed fuzzy theory with the aim of solving problems related to complex systems, depending to human reasoning versus mathematics with classical logic. His main goal was to develop an efficient model for describing the process of natural language processing. Mathematical fuzzy logic proposed by Zadeh (1962) was used to model a variable's uncertainty. The theory of fuzzy logic has received more and more attention due to its good compatibility with other sciences. Given that the criteria's involved in the multi attribute decision making (MADM) problem may have uncertainty, it is therefore recommended to use a fuzzy-logic based decision-making approach for the projects. One of the first models of fuzzy-logic based MADM was fuzzy AHP (Chang 1992). In the fuzzy AHP, using linguistic expressions, the concept of fuzziness is involved in determining pairwise comparison matrices. After the TOPSIS method was developed, many researchers used the TOPSIS method for decision-making and extended this method to the fuzzy TOPSIS (Chen 2000, Yue 2012). However, the use of the fuzzy TOPSIS method for large-scale problems is limited. The fuzzy VIKOR method can also be used for problems where the data are not accurate enough or conclusive. The ranking criteria in this method are based on how close they are to the ideal solution, and also an integral LP metric function is used for compromise ranking. This method can provide a maximum value of group favorability for the majority and a minimum individual impact for the opposition. The normalized values in this method do not depend on the evaluation unit of each criterion because it uses linear normalization. The fuzzy VIKOR method has been successfully applied in the problems. Opricovic (2011) used the fuzzy VIKOR method for water resource planning. Ploskas *et al*. (2017) implemented the extended fuzzy VIKOR method based on triangular and trapezoidal fuzzy linguistic variables. In the present study, by combining fuzzy VIKOR method and game theory, a new method was developed to determine the optimal quantitative and qualitative water allocation of the dam reservoir water.

2.2 The fuzzy VIKOR method

Opricovic (2007) developed the VIKOR method based on fuzzy logic. Steps to solve MCDM problems using fuzzy VIKOR method are as follows: (1) forming the fuzzy decision-making matrix, (2) determining the positive and negative ideal alternatives, (3) determining utility value of each alternative, (4) calculating the VIKOR index, and (5) ranking the alternatives based on the VIKOR index. Each of the problem-solving steps is summarized below:

(1) Forming the fuzzy decision-making matrix:

Based on n criterion $C_j(j = 1,2,\dots,n)$ and the m alternatives $A_i(i = 1,2,\dots,m)$, the fuzzy decision-making matrix and the weight vector would be as follows:

$$\tilde{U} = \begin{pmatrix} \tilde{x}_{11} & \dots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{pmatrix} \tilde{w} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n) \tag{1}$$

where $\tilde{x}_{ij}$ represents the fuzzy importance of the ith alternative with respect to the jth criterion, and $\tilde{w}_j$ denotes the fuzzy weight of the jth criterion.

(2) Determining the positive and negative ideal alternatives:

Positive ideal alternative:

$$\tilde{f}^* = \begin{cases} C_j \to \overset{*}{A} = \max_i\{\tilde{x}_{ij}\}, Posetiveside \\ C_j \to \overset{*}{A} = \min_i\{\tilde{x}_{ij}\}, Negativeside \end{cases} = \left(\tilde{f}_1^{\ *}, \dots, \tilde{f}_n^{\ *}\right) \tag{2}$$

Negative ideal alternative:

$$\tilde{f}^- = \begin{cases} C_j \to A^- = \min_i\{\tilde{x}_{ij}\}, Posetiveside \\ C_j \to A^- = \max_i\{\tilde{x}_{ij}\}, Negativeside \end{cases} = \left(\tilde{f}^-{}_1, \dots, \tilde{f}^-{}_n\right) \tag{3}$$

(3) Determining utility value of each alternative:

Utility value of each alternative represents the distance of that alternative from the positive ideal alternative. These values can be defined using the following equations:

$$\tilde{S}_i = \sum_1^n \left(\tilde{w}_j \times \frac{(\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)}\right) = (v_i\ s_i\ t_i) \tag{4}$$

$\tilde{S}_i$ represents the total distance of the ith alternative from the positive ideal alternative in each criterion with respect to the weight of that criterion.

And

$$\tilde{R}_i = \max_j \left(\tilde{w}_j \times \frac{(\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)} \right) = (p_i \, r_i \, l_i) \quad (5)$$

$\tilde{R}_i$ denotes the longest distance of the ith alternative from the positive ideal alternative.

(4) Calculating the VIKOR index:

$$\tilde{Q}_i = \left(v \times \frac{(\tilde{S}_i - \tilde{S}^*)}{(\tilde{S}^- - \tilde{S}^*)} \right) + \left((1 - v) \times \frac{(\tilde{R}_i - \tilde{R}^*)}{(\tilde{R}^- - \tilde{R}^*)} \right) \quad (6)$$

$$\tilde{S}^* = \min_i \tilde{S}_i \approx \left(\min_i v_i \min_i s_i \min_i t_i \right) = (v^* \, s^* \, t^*) \quad (7)$$

$$\tilde{S}^- = \max_i \tilde{S}_i \approx \left(\max_i v_i \max_i s_i \max_i t_i \right) = (v^- \, s^- \, t^-) \quad (8)$$

$$\tilde{R}^* = \min_i \tilde{R}_i \approx \left(\min_i p_i \min_i r_i \min_i l_i \right) = (p^* \, r^* \, l^*) \quad (9)$$

$$\tilde{R}^- = \max_i \tilde{R}_i \approx \left(\max_i p_i \max_i r_i \max_i l_i \right) = (p^- \, r^- \, l^-) \quad (10)$$

To calculate the VIKOR index, $\frac{(\tilde{S}_i - \tilde{S}^*)}{(\tilde{S}^- - \tilde{S}^*)}$ is the index ratio of the ith alternative from the positive ideal alternative, and $\frac{(\tilde{R}_i - \tilde{R}^*)}{(\tilde{R}^- - \tilde{R}^*)}$ is the index ratio of the ith alternative from the negative ideal alternative. v ranges between zero and one and its value is determined by the decision maker, and often considers to be 0.5. The closer the value of v is to one, the more interested the decision maker is in using the weighted utility and the involvement of all criteria with respect to the maximum utility. When the value of v is equal to 0.5, it indicates the agreement among experts.

(5) Ranking the alternatives based on the VIKOR index:

Each alternative with the smaller VIKOR index ($\tilde{Q}_i$) has a higher priority for the selection. The VIKOR index of each alternative is a triangular fuzzy number, the area method is used to compare $\tilde{Q}_i$. In this case, the alternatives are compared in pairs and they are prioritized based on the smaller VIKOR index.

2.3 The Young's bilateral bargaining model

The evolutionary bargaining games lead people to behavior based on trial and error, which can result in more utility for them. However, this utility may not necessarily be ideal for both parties. The structure of evolutionary bargaining theory is based on the dynamic responses of all parties involved in the negotiation. All players have accepted the change of space they have created together. In practice, during a repeated bargaining process, an appropriate share will be allocated to each player the negotiation strategy according to the chosen strategy of each player versus the chosen strategy of the negotiating parties. The allocated share should be more than that of the player who does not participate in the negotiation so that a person has the necessary motivation to participate in the game. According to this theory, it is assumed that the parties of the game have a limited knowledge of the game and they use rules that ultimately lead to finding the optimal solution available from their limited information. In fact, each player will behave rationally. The repeated (non-cooperative) bargaining game is often done indefinitely. Players are assumed to pay more attention to recent games and reactions, and the effects of previous games are ignored (Napel 2002). Young (1993) conducted the first study on evolutionary model of indefinite bargaining. Young's theory was that the Nash bargaining solution (NBS) for members who reasonably relate to each other could be a good predictor of the outcome of bargaining. The Young's model was proposed in the framework of evolutionary game model. Young considered two limited groups of players I_1, I_2 for each party. For each time period $t \in T = \{0,1,2,\ldots\}$, two agents $J \in I_1$, $K \in I_2$ randomly play a limited two-person game in the role of players 1 and 2, respectively, and it is assumed that the recognition of a player is based on his previously observed activities, and the players' communities are limited, finite and independent. Young assumed that only observations and information related to m ≥ 1 of the recent game were available. The set of combinations of strategies recognized in m past period, $h_t = (s^{t-m+1}, \ldots, s^t)$, is called the memory of society in the period t.

In this method, the strategies of past periods are assessed but not the players. It is assumed that players use only information of part of their memory to make decisions, which may be due to the limited capacity to analyze information by each member. Young also assumed that populations were homogeneous. The bargaining process in the Young's theory was step-by-step and evolutionary and the concept of bargaining was clear. The utility function for each player should be relatively concave, incremental and non-negative and is considered as Neumann–Morgenstern utility function. Therefore, the utility function for each player is considered as (r_i, π_i). It should be noted that the players are not aware of the preferences of other players. Young (1993) showed that the above repetitive and evolutionary game would tend towards a single solution. The solution to the game can be obtained from the maximization of the function as follows:

$$R_{(x)} = \min \left\{ \begin{array}{c} \min mr_j \dfrac{\partial \pi_k (1-x)/\partial x}{\pi_k (1-x)_{k \in I_2}} \\ , \\ \min mr_j \dfrac{\partial \pi_j (x)/\partial x}{\pi_j (x)_{j \in I_2}} \end{array} \right\} \quad (11)$$

where, x represents the share of the player j from group I_1, $1 - x$ denotes the share of player k from group I_2, $\pi_j(x)$ is the utility function for the player j from group I_1 and $\pi_k(1-x)$ is the utility function for the player k from group I_2.

It should be noted that in the model presented by Young, bargaining is about a single product, while in the operation of the reservoir, bargaining is about quality and quantity, which are not the same. Therefore, it is necessary to modify

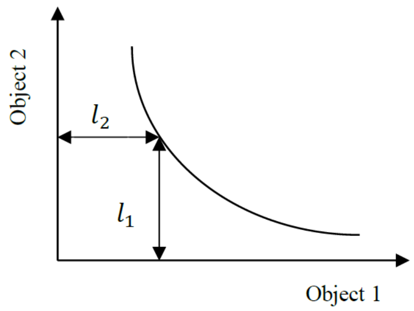

Fig. 1 Showing l_1 and l_2 on the trade-off curve

the relationship provided by Young.

For this purpose, the method proposed by Shirangi *et al*. 2008) was used. In the method proposed by Shirangi *et al*. 2008) to integrate the objectives, changes need to be made to the trade-off curve to obtain the share of each player. As shown in Fig. 1, it was assumed that the share of player j from group I_1 was equal to x_1 and the share of player k from group I_2 was equal to x_2, then $x_1 + x_2 = 1$. x_1, x_2 was defined by relationships as shown in Fig. 1. As the value of x_1 increased, the value of x_2 decreased and vice versa (the values of l_1 and l_2 can be obtained from the trade-off curve).

$$x_1 = \frac{l_2}{l_1 + l_2} \tag{12}$$

$$x_2 = \frac{l_1}{l_1 + l_2} \tag{13}$$

If the utility for each decision maker with respect to the points on the trade-off curve is determined, the optimal point on the trade-off curve can be determined using the Young's theory.

In this paper, considering different criteria, the points on the trade-off curve were first prioritized from the point of view of each decision maker using the fuzzy -logic based decision making method based on the fuzzy VIKOR, and then using the Young's conflict resolution theory, the point was determined on the trade-off curve where the maximum utility for both groups of decision makers met. Using the proposed method, the opinions of stakeholders involved in decision-making were considered according to different criteria in the dam reservoir operation. Because the decision makers considered different factors in addition to quantitative and qualitative criteria, they were willing to participate in bargaining and reconsider their ideals. One of the advantages of the proposed method was that due to the use of the fuzzy -logic based decision making method and considering different factors, the utility of all decision makers was close to each other and the scope of bargaining became smaller, leading to an increase in the possibility of reaching an agreement in a shorter time period using game theory. In this method, all qualitative judgments without considering explicitness of the decision makers were applied to the model using the fuzzy logic. In this study, we evaluated the performance of the proposed method and compared its results with those of models developed by previous studies (Shirangi *et al*. 2008 and Mojarabi-kermani *et al*. 2019). In the present study, 15-Khordad dam of Iran was selected as a case study area.

2.4 Case study

The 15 Khordad dam is located in Iran. Assessing the performance of the proposed model and comparing its results with those of models developed by previous studies was a special reason for selecting this dam. The 15 Khordad dam is a heterogeneous earth dam with a clay core. The 15-Khordad reservoir with a volume of 200 million cubic meters has significant water quality problems. The objectives of its construction and operation are to: (1) provide agricultural water to more than 8,000 ha of downstream land, (2) store floods and (3) provide water for the surrounding cities. This dam is located on the bed of Qomroud river. Qomroud river has flood regime and some of its branches, such as Darband, Khomein and Khansar have snow regime and other branches have rain regime. Water quality of Qomroud river in the 15 Khordad Dam is affected by the quality of the water flow of the rivers and several flood channels that may be due to urban and rural activities, the entry of agricultural drainage water and the industrial effluents.

On the other hand, for reasons, including the consecutive droughts during recent years, thermal stratification in reservoir, poor operation, lake evaporation, poor quality of incoming water (especially due to saline rivers) and poor quality of geological structure of dam reservoir, the water quality of dam's reservoir is very low.

It is therefore recommended to review the studies conducted by Shirangi *et al*. 2008) and Mojarabi-kermani *et al*. 2018, 2019) in order to obtain more information about this dam.

3. Results and discussion

The main problem of the 15-Khordad Dam located in the central part of Iran is the quality of its reservoir, which has caused the two main decision makers to have significant conflicts regarding reservoir operation. In the previous studies, given that the conflicts between the decision makers was resolved only by considering both the quantitative and qualitative criteria; therefore, the flexibility of these two main stakeholders was poor and they actually exhibited a lot of resistance in the negotiations. Considering the effects of three important economic, social and environmental factors on dam reservoir exploitation, in this study, for the first time, these factors were considered in addition to both the quantitative and qualitative criteria. The increase of influential factors has attracted the attention from the decision-makers to the effects of these factors and due to the high sense of responsibility of the decision-makers; their flexibility in negotiations is increased. Therefore, it was possible to reach an agreement quickly, and also a more comprehensive study is presented. After combining both the fuzzy decision-making model and the game theory, the approved TDS value was determined, and

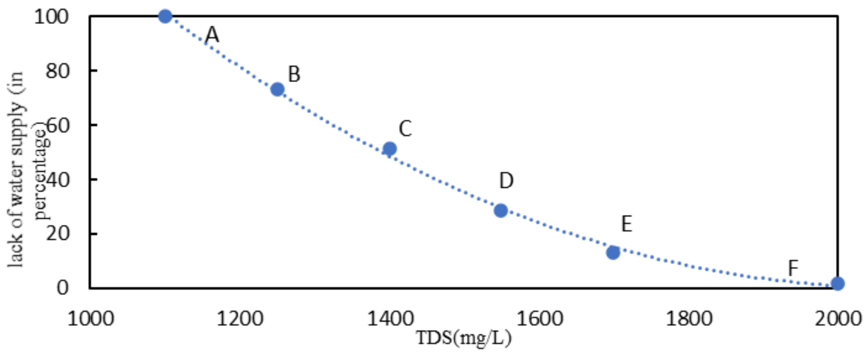

Fig. 1 Showing l_1 and l_2 on the trade-off curve

Table 1 The values of TDS, water supply and non-supply for the six points considered on the trade-off curve

	Alternative					
	A	B	C	D	E	F
TDS (mg/lit)	1100	1250	1400	1550	1700	2000
Water supply (in percentage)	0	26.62	45.7	71.33	92.96	98.15
lack of water supply (in percentage)	100	73.38	54.3	28.67	7.04	1.85

Table 2 Numerical value of the linguistic variables for the criteria from the perspective of the experts of DM1 and DM2

Linguistic variable	From the perspective of the experts of DM1		From the perspective of the experts of DM2	
	The criteria with a positive aspect (+)	The criteria with a negative aspect (-)	The criteria with a positive aspect (+)	The criteria with a negative aspect (-)
Very Low (VL)	1	9	1	9
Low (L)	3	7	3	7
Medium (M)	5	5	5	5
High (H)	7	3	7	3
Very High (VH)	9	1	9	1

also the model was implemented again and the optimal monthly withdrawal rate from the dam reservoir was determined.

Agriculture Organization (DM1) and the Urban Water Supply Organization (DM2) were considered as two main decision makers involved in the operation of the water reservoir behind 15-Khordad dam. After studying the duties of each organization and conducting an interview with their experts, five factors, including the allocated water quantity (A1), the allocated water quality (A2), the economic benefits of water allocation (A3), the social conditions and expectations of the region (A4), and environmental problems (A5) were considered as the key criteria for deciding on the operation of the dam reservoir.

Mojarabi-kermani *et al.* (2019) combined the WQRRS model and the genetic algorithm (GA)-based optimization model and presented an optimal trade-off curve with quantitative and qualitative objectives (Fig. 2). This curve was obtained from the optimization model and consisted of a series of optimal points. The horizontal axis of the trade-off curve showed the TDS in milli gram per liter and its vertical axis indicated the value of water supply/ non-supply in percent. According to the trade-off curve (Fig. 2), there was an inverse relationship between the quantity and the quality. As shown in Fig. 2, in order to reduce computational problems, six optimal points A, B, C, D, E, F were considered on the trade-off curve. As shown in Table 1, each of these points represented a certain value of TDS and the value of water supply/non- supply in percent. TDS was considered as a reservoir water quality indicator. For example, in point B, the value of TDS was 1250 mg/l, the value of water supply was 26.62% and the value of non-supply of water was 73.38%. In the first step, six points A, B, C, D, E, F considering five criteria, including the allocated water quantity (A1), the allocated water quality(A2), the economic benefits of water allocation(A3), the social conditions and expectations of the region(A4), and environmental problems (A5) were ranked from the decision makers' point of view. After conducting an interview with experts of DM1 and DM2, the data given in Table 2 showed the numerical value of the linguistic variable with respect to positive or negative aspects of criteria from their point of view. Given the different utility for the expert representatives of each of these two organizations, the degree of importance of each of these criteria was different from their point of view.

After conducting an interview with the expert representatives of both organizations, the degree of

Table 3 The degree of importance of the optimal points (A, B, C, D, E, F) on the trade-off curve for decision makers involved in agriculture organization (DM1) and the Urban Water Supply Organization (DM2) considering five criteria (A1, A2, A3, A4, A5)

Attribute	Decision maker	Alternative					
		A	B	C	D	E	F
A1	DM1	VL	VL	M	H	VH	VH
	DM2	VH	VH	H	M	L	VL
A2	DM1	VL	VL	M	H	VH	VH
	DM2	VL	VL	L	M	H	VH
A3	DM1	VL	L	M	H	VH	VH
	DM2	VL	M	H	H	VH	VH
A4	DM1	VL	VL	L	M	VH	VH
	DM2	VL	L	M	H	VH	VH
A5	DM1	VL	L	M	H	VH	M
	DM2	VL	H	VH	M	VL	VL

Table 4 The weights of criteria calculated by DM1 and DM2

The weights of criteria	Attribute				
	A1	A2	A3	A4	A5
DM1	0.224	0.224	0.152	0.259	0.141
DM2	0.156	0.244	0.118	0.156	0.326

Table 5 Fuzzy numbers for approximating linguistic variable values

linguistic variable	Fuzzy number
Very Low (VL)	(1,1,3)
Low (L)	(1,3,5)
Medium (M)	(3,5,7)
High (H)	(5,7,9)
Very High (VH)	(7,9,9)

Table 6 Fuzzy decision-making matrix

Attribute	Alternative					
	A	B	C	D	E	F
A1	1100	1250	1400	1550	1700	2000
A2	0	26.62	45.7	71.33	92.96	98.15
A3	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)
A4	(1, 1, 3)	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(7, 9, 9)	(7, 9, 9)
A5	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)

importance of each of the optimal points A, B, C, D, E, F considering the five criteria A1, A2, A3, A4, A5 were determined as shown in Table 3.

Using the entropy method, the weights of criteria were calculated by the decision makers. Table (4) shows the weights of criteria calculated by DM1 and DM2.

The fuzzy VIKOR method was employed to rank the optimal points A, B, C, D, E, F. Table (5) shows fuzzy numbers for approximating linguistic variable values after conducting an interview with the expert representatives of DM1 and DM2.

In Section 3.1, the problem-solving steps using the VIKOR method are presented (tables 6 to 10). The point E considering the five criteria A1, A2, A3, A4, A5 was the best alternative from the perspective of the representative of the DM1. It is worth noting that based on the VIKOR method, an alternative with the lowest VIKOR index showed the highest utility from the decision makers' perspective. As shown in Table 1, the point E had a TDS = 1,700 mg/l and water supply was 92%, which reduced the utility of DM1 by moving to point A. After performing similar calculations using the fuzzy VIKOR method, the

Table 7 Positive and negative ideal alternatives

	Attribute				
	A1	A2	A3	A4	A5
A^*	(2000, 2000, 2000)	(98.15, 98.15, 98.15)	(7, 9, 9)	(7, 9, 9)	(7, 9, 9)
A^-	(1100, 1100, 1100)	(0, 0, 0)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)

Table 8 Alternative's utility value

$S_{i=1,2,\ldots,6}$	S_1= (0.72,0.99,1.54)	S_2= (0.56,0.83,1.45)	S_3= (0.33,0.61,1.23)	S_4= (0.02,0.38,0.85)	S_5= (-0.2,0.08,0.36)	S_6= (-0.2,0.07,0.42)
$R_{i=1,2,\ldots,6}$	R_1= (0.22,0.26,0.52)	R_2= (0.19,0.26,0.52)	R_3= (0.15,0.19,0.52)	R_4= (0.11,0.13,0.39)	R_5= (0.07,0.07,0.13)	R_6= (0.0,0.07,0.21)

Table 9 VIKOR index

	Alternative					
VIKOR index	A	B	C	D	E	F
	Q_1 = (0.2, 1.0, 5.3)	Q_2 = (0.1, 0.9, 5.2)	Q_3 = (0.0, 0.6, 4.9)	Q_4 = (-0.59, 0.3, 3.6)	Q_5 = (-1.1, 0.01, 1.5)	Q_6 = (-1.5, 0.0, 2.0)

Table 10 Ranking the alternatives

Two-to-two comparison of VIKOR index	S_{total}	S_1	S_2	Comparison between S_1 and S_2	Comparison between Q_1 and Q_2
$Q_1 - Q_2$ = (-5.00, 0.09, 5.20)	5.11	2.64	2.46	$S_1 > S_2$	$Q_1 > Q_2$
$Q_1 - Q_3$ = (-4.70,0.39,5.30)	5.02	2.85	2.17	$S_1 > S_2$	$Q_1 > Q_3$
$Q_1 - Q_4$ = (-3.50,0.67,5.90)	4.68	3.23	1.44	$S_1 > S_2$	$Q_1 > Q_4$
$Q_1 - Q_5$ = (-1.30,0.99,6.40)	3.88	3.49	0.37	$S_1 > S_2$	$Q_1 > Q_5$
$Q_1 - Q_6$ = (-1.90,1.00,0.80)	4.34	3.74	0.60	$S_1 > S_2$	$Q_1 > Q_6$
$Q_2 - Q_3$ = (-4.80,0.30,5.20)	5.00	2.75	2.24	$S_1 > S_2$	$Q_2 > Q_3$
$Q_2 - Q_4$ = (-3.50,0.58,5.80)	4.66	3.13	1.51	$S_1 > S_2$	$Q_2 > Q_4$
$Q_2 - Q_5$ = (-1.40,0.90,6.30)	3.86	3.42	0.42	$S_1 > S_2$	$Q_2 > Q_5$
$Q_2 - Q_6$ = (-1.90,0.91,6.70)	4.32	3.66	0.65	$S_1 > S_2$	$Q_2 > Q_6$
$Q_3 - Q_4$ = (-3.70,0.28,5.50)	4.57	2.86	1.70	$S_1 > S_2$	$Q_3 > Q_4$
$Q_3 - Q_5$ = (-1.50,0.60,6.40)	3.77	3.21	0.55	$S_1 > S_2$	$Q_3 > Q_5$
$Q_3 - Q_6$ = (-2.10,0.61,6.40)	4.23	3.43	0.79	$S_1 > S_2$	$Q_3 > Q_6$
$Q_4 - Q_5$ = (-2.10,0.32,4.80)	3.42	2.51	0.90	$S_1 > S_2$	$Q_4 > Q_5$
$Q_4 - Q_6$ = (-2.60,0.33,5.20)	3.89	2.72	1.16	$S_1 > S_2$	$Q_4 > Q_6$
$Q_5 - Q_6$ = (-3.20,0.01,3.00)	3.09	1.51	1.57	$S_1 < S_2$	$Q_5 < Q_6$

point C was the optimal alternative DM1 on the trade-off curve for DM2, which reduced the utility of DM2 by moving from C to F. As shown in Table 1, point C had TDS=1, 400 mg/l and water supply was 42%.

3.1 The steps of problem solving

(1) Forming the fuzzy decision-making matrix: Table 6
(2) Determining the positive and negative ideal alternatives: Table 7
(3) Determining each alternative's utility value: Table 8
(4) Calculating the VIKOR index: Table 9
(5) Ranking the alternatives based on the VIKOR index: Table 10
(6) The results of the final ranking in terms of the agricultural sector: $Q_1 > Q_2 > Q_3 > Q_4 > Q_6 > Q_5 \Rightarrow E > F > D > C > B > A$

The major advantage of the proposed method was that in addition to considering quantitative and qualitative criteria, social, economic and environmental factors were also considered for the decision makers and stakeholders involved in the operation of 15 Khordad dam reservoir, and also decision-makers bargained with each other in a shorter distance (from E to C) with respect to their ideal distance (from F to A) and this could increase the accuracy and speed of solving the problem. After ranking the optimal points on the trade-off curve, to determine the utility function for each decision maker, the values x_1, x_2 were calculated using Eqs. (12) and (13). After conducting interviews, the utility of each stakeholder for points was determined in the range between E and C considering to the values x_1, x_2. Table (11) shows the details of the calculations based on Young's theory. According to Young's

Table 11 showing the details of the calculations based on Young's theory

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
x_1	$u(x_1)$	$\frac{\partial u(x_1)}{\partial x_1}$	$\frac{a\frac{\partial u(x_1)}{\partial x_1}}{u(x_1)}$	x_2	$V(x_2)$	$\frac{\partial V(x_2)}{\partial x_2}$	$\frac{b\frac{\partial V(x_2)}{\partial x_2}}{V(x_2)}$	$R(x)$ Min (4), (8)	
62.05	59.61	1.35	0.02258	37.95	99.55	1.72	0.017244	0.017244	
66.26	65.36	1.38	0.02115	33.74	91.27	2.21	0.024254	0.021150	Max
70.60	71.44	1.42	0.01985	29.40	80.55	2.73	0.033841	0.011985	
75.08	77.87	1.45	0.01866	24.92	67.15	3.25	0.048462	0.011866	
79.69	84.64	1.49	0.01758	20.31	50.91	3.80	0.074601	0.01758	
84.41	91.76	1.52	0.01660	15.59	31.64	4.36	0.137659	0.01660	
89.27	99.00	1.56	0.01570	10.73	9.10	4.93	0.54146	0.01570	

theory, a certain value for x_1, x_2 was determined as shown in Eqs. (12) and (13), so that the value of $R(x)$ was maximized.

As shown in Table 11, the maximum value of $R(x)$ was 0.02115. As a result, the optimal values for x_1, x_2 were approximately 66.26 and 33.74, respectively. According to the equation, the relationship between l_1 and l_2 should be such that based on the trade-off curve, a point associated with l_1 and l_2 can be easily determined. At this point, water supply for TDS = 1, 490 mg/L was 65%. Also, the monthly time series of water withdrawal of each of the dam valves can be determined based on the optimal point obtained from this method. The model for TDS agreed between the decisions makers was re-implemented and the monthly time series of water withdrawal of the reservoir was determined for a 30-year period. After comparing the results of this method with those of the model presented by Shirangi *et al*. 2008), it was found that the value of TDS agreed between the players was similar and no significant changes were made in the responses. With this difference that in the proposed method, different criteria from the stakeholders' point of view were considered for the optimal allocation of reservoir water. Comprehensiveness and reduced speed of the implementation of the model were the advantages of the proposed model. Developing a new method combining decision fuzzy-logic based decision-making method and the Young's bilateral bargaining model, due to its comprehensiveness (considering all social, economic and environmental criteria) and shortening the bargaining time with increasing accuracy in determining the TDS value on the trade-off curve was one of the advantages of this study. This method can be used for the exploitation of water resource systems that have multiple decision makers with different utilities and usually conflicting objectives, and is a new way to reduce the conflicts among decision makers, especially in areas that have minor problems. In this research and in the discussion of, only two groups of main decision-makers who has very high decision-making power were considered in the 15 Khordad dam reservoir operation, while there were also public or private organizations who had lower decision-making power and sometimes had common or conflicting interests. It is therefore recommended that the presence of these stakeholders in negotiations should be considered in future studies and the collective bargaining should be used for modeling.

4. Conclusions

In this study, by combining the fuzzy-logic based decision-making method and the Young's bilateral bargaining model, a new method was developed to determine the optimal quantitative and qualitative water allocation of the dam reservoir. In the proposed method, after conducting an interview with experts involved in the operation of the dam reservoir and determining their utility, for the first time, using the fuzzy VIKOR method, the optimal points on the trade-off curve obtained from a study conducted by Mojarabi-kermani *et al*. 2019) were ranked. Using the Young's bilateral bargaining model, the optimal point on the trade-off curve agreed between the negotiating parties was determined. For each optimal point agreed between the parties, the monthly time series of water withdrawal of the dam reservoir for the desired quality was determined in a specific time period. Developing a new method combining decision fuzzy-logic based decision-making method and the Young's bilateral bargaining model, due to its comprehensiveness (considering all social, economic and environmental factors) and shortening the bargaining time with increasing accuracy in determining the point agreed between the decision makers was one of the advantages of this study. The results of this study can be considered as an important step towards the expansion of previous studies.

References

Abdi-Dehkordi, M., Bozorg-Haddad, O., Salavitabar, A. and Goharian, E. (2021), "Developing a sustainability assessment framework for integrated management of water resources systems using distributed zoning and system dynamics approaches", *Environ. Develop. Sust.*, **23**, 16246-16282. https://doi.org/10.1007/s10668-021-01340-0

Al-Furjan, M.S.H., Keshtegar, B., Kolahchi, R. and Trung, N.T. (2021a), "Dynamic stability control of viscoelastic nanocomposite piezoelectric sandwich beams resting on Kerr foundation based on exponential piezoelasticity theory", *Eur. J. Mech. A Solids.*, **86**, 104169.

https://doi.org/10.1016/j.euromechsol.2020.104169.

Al-Furjan, M.S.H., Farrokhian, A., Mahmoud, S.R. and Kolahchi, R. (2021b) "Dynamic deflection and contact force histories of graphene platelets reinforced conical shell integrated with magnetostrictive layers subjected to low-velocity impact", *Thin Wall. Struct.*, **163**, 107706. https://doi.org/10.1016/j.tws.2021.107706.

Babamiri, O. and Marofi, S. (2021), "A multi-objective simulation–optimization approach for water resource planning of reservoir–river systems based on a coupled quantity–quality model", *Environ. Earth Sci.*, **80**, 389. https://doi.org/10.1007/s12665-021-09681-9.

Babamiri, O., Azari, A. and Marofi, S. (2022), "An integrated fuzzy optimization and simulation method for optimal quality-quantity operation of a reservoir-river system", *Water Supply.*, **22**(4), 4207-4229. https://doi.org/10.2166/ws.2022.045.

Bazargan-Lari, M.R., Kerachian, R. and Mansoori, A. (2009), "A conflict-resolution model for the conjunctive use of surface and groundwater resources that considers water-quality issues: A case study", *Environ. Manage.*, **43**(3), 470-482. https://doi.org/10.1007/s00267-008-9191-6.

Bin, O., Aimin, G., Chunxiang, H. and Shuyan, F. (2019), "Dynamic evaluation of water source safety based on fuzzy extension model", *Membr. Water Treat.*, **10**(2), 149-154. https://doi.org/10.12989/mwt.2019.10.2.149.

Chang, D.Y. (1992), "Extent analysis and synthetic decision" *Opt. Techniq. Appl.*, **1**, 352-355.

Chen, C.T. (2000), "Extensions of the TOPSIS for group decision-making under fuzzy environment", *Fuzzy Set. Syst.*, **114**(1), 1-9. https://doi.org/10.1016/S0165-0114(97)00377-1.

Darbandsari, P., Kerachian, R., Malakpour-Estalaki, S. and Khorasani, H. (2020), "An agent-based conflict resolution model for urban water resources management", *Sust. Cities Soc.*, **57**. https://doi.org/10.1016/j.scs.2020.102112.

Dursun, M., Karsak E.E. and Karadayi, M.A. (2011), "Assessment of health-care waste treatment alternatives using fuzzy multi-criteria decision making approaches", *Resour. Conserv. Recycl.*, **57**, 98-107. https://doi.org/10.1016/j.resconrec.2011.09.012.

En-Nasyry, A., Chiron, P. and Archimede, Bernard. (2020), "Remediation of accidental river pollution: strategies based on the use of reservoirs", *IFAC Papers OnLine.*, **53**(2), 16605-16610. https://doi.org/10.1016/j.ifacol.2020.12.788.

Eyni, A., Emami Skardi, M.J and Kerachian, R. (2021), "A regret-based behavioral model for shared water resources management: Application of the correlated equilibrium concept", *Sci. Total Environ.*, **759**, 143892. https://doi.org/10.1016/j.scitotenv.2020.143892.

Haghighat, M., Nikoo, M.R., Parvinnia, M. and Sadegh, M. (2021), "Multi-objective conflict resolution optimization model for reservoir's selective depth water withdrawal considering water quality", *Environ. Sci. Pollut. Res.*, **28**, 3035-3050. https://doi.org/10.1007/s11356-020-10475-y.

Hajmohammad, M.H., Kolahchi, R., Sharif Zarei, M. and Maleki, M. (2018a), "Earthquake induced dynamic deflection of submerged viscoelastic cylindrical shell reinforced by agglomerated CNTs considering thermal and moisture effects", *Compos. Struct.*, **187**, 498-508. https://doi.org/10.1016/j.compstruct.2017.12.004.

Hajmohammad, M.H., Maleki, M. and Kolahchi, R. (2018b), "Seismic response of underwater concrete pipes conveying fluid covered with nano-fiber reinforced polymer layer", *Soil Dyn. Earthq. Eng.*, **110**, 18-27. https://doi.org/10.1016/j.soildyn.2018.04.002.

Hati, S. and Panda, S.K. (2021), "Pareto optimality and game theory for pile design having conflicting objectives", *Geomech. Eng.*, **27**(1), 65-76. https://doi.org/10.12989/gae.2021.27.1.063.

Hwang, C.L. and Yoon, K. (1981), *Multiple attribute decision making: methods and applications*, Springer-Verlag, Berlin.

Karimi, A., Nikoo, M. R., Kerachian, R., and Shirangi, E. (2011), "Assessment of water transport projects impact on long term water supply in Zayandehrood basin by multi-period optimization analysis", *Iran. Water Res. J.*, **6**(11), 153-163.

Kerachian, R. and Karamouz, M. (2006), "Optimal reservoir operation considering the water quality issues: A stochastic conflict resolution approach", *Water Resour. Res.*, **42**, 1-15. https://doi.org/10.1029/2005WR004575.

Kerachian, R. and Karamouz, M. (2007), "A stochastic conflict resolution model for water quality management in reservoir-river systems", *Adv. Water Resour.*, **30**(4), 866-882. https://doi.org/10.1016/j.advwatres.2006.07.005.

Kerachian, R. and Shirangi, E. (2008), "A case study for conflict resolution in reservoir operation for water quantity and quality", *World Water Environ. Resour. Congress, Hawaii*.

Keshtegar, B., Farrokhian, A., Kolahchi, R. and Trung, N.T. (2020a), "Dynamic stability response of truncated nanocomposite conical shell with magnetostrictive face sheets utilizing higher order theory of sandwich panels", *Eur. J. Mech. A Solids.*, **82**, 104010. https://doi.org/10.1016/j.euromechsol.2020.104010.

Keshtegar, B., Motezaker, M., Kolahchi, R. and Trung, N. T. (2020b), "Wave propagation and vibration responses in porous smart nanocomposite sandwich beam resting on Kerr foundation considering structural damping", *Thin Wall. Struct.*, **154**, 106820. https://doi.org/10.1016/j.tws.2020.106820.

Kheirkhah Hasanzadeh, S., Saadatpour, M. and Afshar, A. (2020), "A fuzzy equilibrium strategy for sustainable water quality management in river-reservoir system", *J. Hydrol.*, **586**, 124892. https://doi.org/10.1016/j.jhydrol.2020.124892.

Khorsandi, M., Ashofteh, P.S. and Azadi, F. (2022), "Multi-objective firefly integration with the K-nearest neighbor to reduce simulation model calls to accelerate the optimal operation of multi-objective reservoirs", *Water Resour Manage.*, **36**, 3283-3304. https://doi.org/10.1007/s11269-022-03201-5.

Kolahchi, R. and Kolahdouzan, F. (2021), "A numerical method for magneto-hygro-thermal dynamic stability analysis of defective quadrilateral graphene sheets using higher order nonlocal strain gradient theory with different movable boundary", *Appl. Math. Modell.*, **91**, 458-475. https://doi.org/10.1016/j.apm.2020.09.060.

Kolahchi, R., Zhu, S.Z., Keshtegar, B. and Trung, N.T. (2020), "Dynamic buckling optimization of laminated aircraft conical shells with hybrid nanocomposite martial", *Aerosp. Sci. Technol.*, **98**, 105656. https://doi.org/10.1016/j.ast.2019.105656.

Malekmohammadi, B., Zahraei, B. and Kerachian, R. (2011), "Ranking solutions of multi-objective reservoir operation optimization models using multi-criteria decision analysis", *Expert Syst. Appl.*, **38**(6), 7851-7863.

Mardani Najafabadi, M., Mirzaei, A. and Azarm, H. (2022), "Managing water supply and demand to achieve economic and environmental objectives: Application of mathematical programming and ANFIS models", *Water Resour Manage.*, **36**, 3007-3027. https://doi.org/10.1007/s11269-022-03178-1.

Mojarabi-Kermani, A.R., Shirangi, E., Bordbar, A., Kaman Bedast, A.A. and Masjedi, A.R. (2018), "Modeling of decision-makers negotiations in reservoir operation with respect to water quality and environmental issues", *Membr. Water Treat.*, **9**(6), 421-434. https://doi.org/10.12989/mwt.2018.9.6.421.

Mojarabi-Kermani, A.R., Shirangi, E., Bordbar, A., Kaman Bedast, A.A. and Masjedi, A.R. (2019), "Stochastic optimal reservoir operation management, applying group conflict resolution model", *Water Resour. Manag.*, **33** (8), 2847-2865. https://doi.org/10.1007/s11269-019-02271-2.

Mosadeghi, R., Warnken, Tomlinson, R. and Mirfendersk, H. (2012), "Uncertainty analysis in the application of multi-criteria decision-making methods in Australian strategic environmental decisions", *J. Environ. Plan. Manag.*, **56**(8), 1097-1124. https://doi.org/10.1080/09640568.2012.717886.

Napel, S. (2002), Bilateral Bargaining: Theory and Applications. Springer-Verlag, Berlin.

Nikoo, M.R., Gavahi, K. and Khoramshokooh, N. (2019), "A multi-objective simulation–optimization approach for design of cutoff walls and apron of diversion dams", *Iran J. Sci. Technol. Trans. Civil Eng.*, **43**, 241-252. https://doi.org/10.1007/s40996-018-0134-z.

Niksokhan, M.H., Kerachian, R. and Amin, P. (2009), "A stochastic conflict resolution model for trading pollutant discharge permits in river systems", *Environ. Monitor. Assess.*, **154**(1), 219-232. https://doi.org/10.1007/s10661-008-0390-7.

Niu, W.J., Feng, Z.K. and Li, Y.R. (2021), "Cooperation search algorithm for power generation production operation optimization of cascade hydropower reservoirs", *Water Resour. Manage.*, **35**, 2465-2485. https://doi.org/10.1007/s11269-021-02842-2.

Opricovic, S. (1998), *Multicriteria Optimization of Civil Engineering Systems*, Faculty of Civil Engineering, Belgrade.

Opricovic, S. (2007), "Fuzzy VIKOR with an application to water resources planning", *Expert Syst. Appl.*, **38**(10), 12983-12990. https://doi.org/10.1016/j.eswa.2011.04.097.

Opricovic, S. and Tzeng, G.H. (2011), "Extended VIKOR method in comparison with outranking methods", *Eur. J. Operat. Res.*, **178**(2), 514-529. https://doi.org/10.1016/j.ejor.2006.01.020.

Olson, D.L. (2004), "Comparison of weights in TOPSIS models", *Math. Comput. Modell.*, **40**(7-8), 721-727. https://doi.org/10.1016/j.mcm.2004.10.003.

Peche, R. and Rodríguez, E. (2009), "Environmental impact assessment procedure: A new approach based on fuzzy logic", *Environ. Impact Assess. Rev.*, **29**(5), 275-283. https://doi.org/10.1016/j.eiar.2009.01.005.

Ploskas, N., Papathanasiou, J. and Tsaples, G. (2017), "Implementation of an extended fuzzy VIKOR method based on triangular and trapezoidal fuzzy linguistic variables and alternative deffuzification techniques", *Proceedings of the Decision Support Systems VII. Data, Information and Knowledge Visualization in Decision Support Systems: Third International Conference*, ICDSST 2017, Namur, Belgium, May.

Rashidi, B., Shirangi, E. and Baymaninezhad M. (2018),"Multiple criteria decision making method for selecting of sealing element for earth dams considering long and short terms goals", *Wind Struct.*, **26**(2), 69-74.

Rousis, K., Moustakas, k., Malamis, S., Papadopoulos, A. and Loizidou, M. (2008), "Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus", *Waste Manag.*, **28**(10), 1941-1954. https://doi.org/10.1016/j.wasman.2007.12.001.

Saadatpour, M., Afshar, A. and Sandoval Solis, S. (2020), "Surrogate-based multiperiod, multiobjective reservoir operation optimization for quality and quantity management", *J. Water Resour. Plan Manag.*, **146**(8).

Soltani, M. A., Karimi, A., Bazargan-lari, M. R. and Shirangi, E. (2008), "Stochastic multi-purpose reservoir operation planning by scenario optimization and differential evolutionary algorithm", *J. Appl Sci.*, **8**(22), 4186-4191.

Soltani, F., Kerachian, R., and Shirangi, E. (2010), "Developing operating rules for reservoirs considering the water quality issues: Application of ANFIS-based surrogate models", *Expert Syst. Appl.*, **37**, 6639-6645. https://doi.org/10.1016/j.eswa.2010.03.057.

Shirang, E. and Kerachian, R. (2007), "A simplified model for optimal reservoir operation considering the water quality issues", *Proceedings of CEMEPS/SECOTOX Conference*, Skiathos Island, Greece, June.

Shirangi, E., Kerachian, R. and Shafai Bajestan, M. (2008), "A simplified model for optimal reservoir operation considering the water quality issues: Application of the Young conflict resolution theory", *Environ Monit. Assess.*, **146**, 77-89. https://doi.org/10.1007/s10661-007-0061-0.

Shirangi, E., khaleghi, S., Baghaei, F., Mansoori, A. and Pourmand, E. (2016), "Developing real time optimal reservoir operation rules using bayesian networks: Application of group conflict resolution model", *J. Water Soil Resour. Conserv.*, **5**, 1-11.

Shirangi, M. J., Babazadeh, H., Shirangi, E. and Saremi, A. (2023), "Determining qualitative-quantitative optimal exploitation policies of the dam reservoir by combining the decision-making model based on fuzzy logic and game theory: A case study of the 15 Khordad Dam", *Iran. Water Res. J.*, **17**(1). https://doi.org/10.22034/iwrj.2022.14151.2477

Sedighkia, M., Datta, B. and Abdoli, A. (2022), "Reducing impacts of rice fields nitrate contamination on the river ecosystem by a coupled SWAT reservoir operation optimization model", *Arab. J. Geosci.*, **15**, 160. https://doi.org/10.1007/s12517-022-09439-y.

Sedighkia, M. and Datta, B. (2022), "Using evolutionary algorithms for continuous simulation of long-term reservoir inflows", *Proceedings of the Institution of Civil Engineers - Water Management.*, **175**(2), 67-77. https://doi.org/10.1680/jwama.20.00128.

Vanda, S., Nikoo, M.R., Hashempour, P., Al-Wardy, M., Adamowski, J.F., Simůnek, J. and Gandomi, A.H. (2022), "Reservoir operation under accidental MTBE pollution: A graph-based conflict resolution framework considering spatial-temporal-quantitative uncertainties", *J. Hydrol.*, **605**, 127313. https://doi.org/10.1016/j.jhydrol.2021.127313.

Young, H.P. (1993), "An evolutionary model of bargaining", *J. Econ. Theory*, **59**(1), 145-168. https://doi.org/10.1006/jeth.1993.1009

Yue, Z. (2012), "Extension of TOPSIS to determine weight of decision maker for group decision making problems with uncertain information", *Expert Syst. Appl.*, **39**(7), 6343-6350. https://doi.org/10.1016/j.eswa.2011.12.016.

Zanjanian, H., Niksokhan, M.H. Ghorbani, M. and Rezaei, A.R. (2022), "A novel framework for water right conflict resolution considering actors' power and inter-organizational relationships analysis", *J. Hydroinform.*, **24**(3), 622-641. https://doi.org/10.2166/hydro.2022.166.

Zhang, Y.F. and J. Thorburn, P. (2022), "A deep surrogate model with spatio-temporal awareness for water quality sensor measurement", *Expert Syst. Appl.*, **200**, 116914. https://doi.org/10.1016/j.eswa.2022.116914.

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