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Development of a genetic algorithm-based graph model for conflict resolution for optimizing resolutions in environmental conflicts

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ABSTRACT

Graph model for conflict resolution (GMCR) is a robust tool for resolving disagreements among parties with contradictory interests in a potential conflict. In GMCR, decision-makers (DMs) and their preferences are determined. The DMs are defined as people, parties, or groups having the authority to make decisions and the power to get these decisions approved. This definition excludes some potential stakeholders with no ability to make and exert decisions, like the natural environment. Therefore, this study aims to find an impartial viewpoint representing the natural environment's interests. A new GMCR based on genetic algorithm (GA) optimization is proposed to modify and optimize the final resolution of the GMCR regarding natural environment benefits. Having been applied to a real-world case study, this methodology showed competence in satisfying the fundamental interests of the natural environment to an acceptable extent. This case study is about an endangered seasonal lake, where there is contention between the governmental and agricultural sectors. The results revealed that the disagreement between two conflicting groups could be resolved by modifying the current agreement to consider both groups' demands. Finally, GA, incorporated in GMCR, proved to be a robust optimization technique in complex environmental conflicts.

Key words: conflict resolutions, genetic algorithm (GA), graph model for conflict resolution (GMCR), Jazmurian seasonal lake, natural environment, optimization

HIGHLIGHTS

- Application of intelligence-based game theory in resolving complex water conflicts.
- Robust application of genetic algorithm (GA) optimization capability in water and environmental issues.
- Data-based negotiation methodology for management of interrelated water issues and controversies.
- Improving graph model for conflict resolution (GMCR), as a robust tool, to deal with complex water decision-making processes.

1. INTRODUCTION

The graph model for conflict resolution (GMCR) has been successfully and extensively applied to many conflict problems to achieve stable resolutions (Gopalakrishnan *et al.* 2005; Kinsara *et al.* 2014; Xu *et al.* 2018; Yousefi *et al.* 2019; Yu *et al.* 2019; Shahbaznezhadfard *et al.* 2021). However, a potential area of the GMCR approach that can be improved is decision-makers (DMs) description since it necessitates excluding every stakeholder who cannot make or execute decisions. Accordingly, the experts classify conflicting DMs into three categories: people, executives, and government stakeholders (Sarhadi *et al.* 2019). On the other hand, it is also emphasized that every environmental conflict, especially water-related issues, should be considered a system, entailing two subsystems: the human and the natural environment (Shahbaznezhadfard *et al.* 2021).

Although the majority of GMCR applications have been assigned to environmental issues (Hipel & Fang 2020), the lack of natural environment presence is evident in many cases (Shahbaznezhadfard *et al.* 2021). As mentioned above, when DMs are defined in a conflict model, it is emphasized that they have to be able to make decisions and be powerful enough to implement these decisions (Xu *et al.* 2018). As a result, 'the natural environment' is not included in the main list of DMs in a given conflict. Although, in some cases, environmental-related organizations (either governmental or non-governmental) are considered the main DMs, because of the subjectivity inherited in the decision-making process (Maier *et al.* 2014), the real interests of the environment might be neglected.

Moreover, many involved DMs in a conflict prefer not to consider the natural environment as a stakeholder or DM. This approach stemmed from the fact that the natural environment is not a human and cannot personally participate in the decision-making process. Moreover, considering the natural environment can incur extra investment on the other DMs (Chinyio & Olomolaiye 2009; Hammond & Booth 2010). Consequently, there is a need to improve the GMCR methodology further to include the environment's preferences as one of the key DMs and to better represent the natural environment subsystem. To find true and tangible interests and the preferences of the natural environment, evolutionary algorithms (EAs) can be used since their efficiency and objectivity in finding the most appropriate solutions have been approved for more than five decades (Holland 1992; Karamouz *et al.* 2014; Minaee *et al.* 2019; Huang *et al.* 2020).

Recent EAs have also been modeled to overcome more complex and demanding optimization problems. For instance, Zheng *et al.* (2022) proposed a switch-based surrogate-assisted evolutionary algorithm to address noisy expensive multi-objective problems. Water resources management and the reservoir performance improvement have been improved in research developing new multi-objective and metaheuristic algorithms (Yoosefdoost *et al.* 2022). The problem of finding the most optimal solution for sparse large-scale multi-objective optimization problems has been addressed in a research study conducted by Zou *et al.* (2023). Their proposed algorithm is based on dynamic sparse grouping.

In addition, EAs have been applied for the optimization of many environmental problems, including water resources systems (the main focus of the present study), for more than three decades (Nicklow *et al.* 2010; Maier *et al.* 2014; Zhou *et al.* 2015; Li & Parrott 2016; Lalehzari & Kerachian 2020; Cheng *et al.* 2021; Sharifazari *et al.* 2021). Among the most popular EAs, genetic algorithm (GA) has been applied to various single and multi-objective problems with impressive success (Tao *et al.* 2021). GA is an evolutionary-based approach to finding the most suitable solutions for a given problem. By using three major operators, i.e. selection, crossover, and mutation, GA is able to generate the fittest solutions according to a given objective function (Booker *et al.* 1989; Minaee *et al.* 2019). Water distribution systems are among the areas that make use of GAs to improve performance (Ahmed & Sarma 2005; Mathur & Nikam 2009; Li *et al.* 2012, 2021; Maier *et al.* 2014; Bi *et al.* 2015; Korkana *et al.* 2016; Do *et al.* 2017; Naghdi *et al.* 2021).

Accordingly, the objectives of this paper include: (i) Introducing the natural environment as an inseparable DM for any given water and/or environmental conflict. (ii) Providing a reliable procedure to find the most desirable preference from an environmental perspective. In this framework, by using a GA-based GMCR in one conflicting water reservoir in Iran, the authors try to incorporate 'the environment' as a crucial DM in every potential conflict.

This study has potential limitations. The actual preferences of two conflicting groups were conjectured for the lack of access to these sectors' representatives. Also, it was a challenging task to obtain the data needed for GA development. Moreover, although the results were validated, it should be taken into account that similar studies about the Jazmurian lake focused on other areas that are not the same as the current study field of interest. It is suggested that future studies be devoted to investigating the water share of the Jazmurial lake survival without compromising other sectors' shares.

2. LITERATURE REVIEW

Conflicts are the inevitable outcomes of disagreements, when two or more involved parties find the other parties' interests in contrast with theirs, and the GMCR approach has been successfully and efficiently applied to a large and growing body of problems and conflicts (Rêgo *et al.* 2021). In 1985, Kilgour *et al.* published a paper in which the water allocation problem between the United States and Canada was addressed. They used the GMCR concept to determine all participants' preferences and find the most appropriate ones. The mathematical procedures in this research are fundamental to identical succeeding works (Kilgour *et al.* 1985).

Hipel *et al.* (1997) demonstrated that GMCR II was a more convenient and user-friendly tool than its previous predecessor, i.e. conventional GMCR. The researchers specifically emphasized that environmental conflicts related to water and natural resources management and land use can be successfully addressed by employing GMCR II. In practice, they proved their position by applying it to a real-world water conflict between Canada and the United States.

A transboundary groundwater conflict is the central focus of a study by Philpot *et al.* (2016), in which the authors found that GMCR is a useful method in resolving seemingly intractable water resources conflicts. They identified several DMs with conflicting preferences, among them two main stakeholders were chosen to represent the GMCR DMs. After employing GMCR, the researchers concluded that the most desirable option could be achieved by changing the incentives and encouraging DMs to change their preferences.

By drawing on the concept of inverse engineering, Garcia & Hipel (2017) pave the way for analysts to predict the DMs' actions resulting in a desired solution. According to this study, finding DMs' preferences is a demanding part of the GMCR approach due to several reasons including DMs' reluctance to divulge their preferences and their uncertainty about their real preferences. Analysts can use several methods to compensate for these shortcomings; guessing a DM's preferences by studying its behavior is one of these methods. Furthermore, by detecting the most favorable solution and using inverse GMCR, the preferences that result in this certain solution can be determined.

Dam construction and water allocation in Iran have been discussed in a survey carried out by Zanjanian *et al.* (2018). Although water quotas of each stakeholder have been determined by governmental regulations, trespassing these accepted rules by some parties has led to a complicated conflict among stakeholders in Ilam's dam water allocation problem. By applying the analytical hierarchy process (AHP) method, stakeholders' preferences have evaluated and quantified as the first step of the GMCR approach. The next step of this research includes GMCR procedures to prioritize the preferences and find the most desirable solutions. Two contradictory solutions have been identified as the most stable ones. However, between these two final solutions, the most desirable one is to be selected. Zanjanian *et al.* (2018) suggest that by using the inverse GMCR and specifying a third party as the arbitrator, the most favorable solution can be obtained. Potential power and authority of a DM are of great significance in conflict problems and unfortunately Iran's environmental organizations are almost in a weaker position compared to their counterparts in other sectors. In Ilam's dam water allocation, Zanjanian *et al.* (2018) also observed that other stakeholders (including agricultural and household sectors) are reluctant to release environmental water share, since their power of action outweigh that of the environmental sector.

To analyze the role of power and the relations among actors, Zanjanian *et al.* (2022) applied social network analysis (SNA) along with the GMCR in a case study of water allocation in Iran. However, their result shows that the probable equilibrium will not be inclined toward satisfying the ecosystem and environmental water.

Artificial intelligence (AI) and machine learning (ML) techniques have an unavoidable application in water and environmental modelings (Shourian *et al.* 2008; Mousavi & Shourian 2010; Eslamian *et al.* 2012; Bazrkar & Chu 2022). One of the most important ones is the GA that is combined with GMCR and used in Taravatrooy *et al.*'s research of 2019, in which the reduction of groundwater pollutants and contaminants is considered. In this study, GA is used to optimize all stakeholders' preferences according to their most desirable solutions. For instance, the cost optimization is the most required issue regarding the Ministry of Energy point of view. The Department of Environment, on the other hand, is more concerned about reducing the concentration of the contaminants to not violate the standard measurements. GA is applied to satisfy these stakeholders' concerns. The GMCR approach is also used to find the most preferable option among various alternatives acquired by a fuzzy method combined with GA (Taravatrooy *et al.* 2019).

Pournabi *et al.* (2021) provide a useful method for resolving the quadratic knapsack problem by merging conflict graphs and a swarm optimization-based algorithm. According to their study's results, Pournabi *et al.* (2021) maintain that the optimization process can either repair the infeasibility of graph solutions or improve solutions' quality.

An innovative integrated GMCR method has also been proposed by Dowlatabadi *et al.* (2020) for resolving a transboundary water resource conflict between three countries, namely Iran, Iraq, and Turkey. In the proposed method, AHP methodology and DEMATEL process are used to rank and weigh the preferences, respectively. As a consequence, the input preferences into GMCR are more accurate and reliable. Another innovation proposed by this research is the usage of economic incentives as the conflict settlers for the involved countries.

The optimization process and the inverse graph model have been used in a case study carried out by Han *et al.* (2020). In order to address the problem of asymmetric information in an ongoing conflict, which can result in misperception and abnormal outcomes, Han *et al.* (2020) adopted an inverse graph model to guess the real preferences of stakeholders and optimize the obtained resolutions. They successfully apply their proposed method to a real-life case study to confirm the results.

A recent study by Rêgo *et al.* (2021) involved an inverse GMCR to find the potential preferences for obtaining a desired solution, thereby optimizing costs of changing the preferences for each DMs. They successfully applied their proposed model to the Cuban missile crisis. Unlike the traditional graph model, the inverse GMCR starts with the desired solution and finds the preferences, resulting in this solution. Therefore, the current preferences can be manipulated to achieve the desired outcome (Rêgo *et al.* 2021).

Two water resource conflict cases are studied in research conducted by Bahrini *et al.* (2021). In this study, GMCR methodology is used to model these two conflicts. Social choice voting rules are also utilized to sieve the socially optimal outcomes from the results of the graph model. Finally, a new approach called 'Related Games' is applied to evaluate the impacts of leading games on the consequential games' outcomes.

Another enhanced GMCR method is used by Pournabi *et al.* (2021) investigating the same case study as Dowlatabadi *et al.* (2020) – transboundary water conflict between Iran, Iraq, and Turkey – from an internal and national point of view. According to this study, national organizations' mismanagement and disagreement have exacerbated the severity of this conflict. Therefore, GMCR is used to resolve the ongoing disagreement between internal organizations, while AHP and SWOT approaches are also used to determine, evaluate, and prioritize DMs' preferences.

Based on the literature review, it can be concluded that GMCR methodology is a robust approach having been applied to many environmental and non-environmental cases. Undoubtedly, the utilization of GMCR can assist every researcher to find the most appropriate resolution for a given conflict and help the conflict to be resolved. On the other hand, optimization algorithms and approaches are also useful methods to combine with the classic GMCR and enhance its performance. The present study aims to integrate an optimization method (GA) with GMCR to improve and optimize the obtained resolutions based on an environmental point of view.

3. METHODOLOGY

3.1. Proposed methodology

In this study, the GMCR approach has been modified to incorporate the natural environment as one of the crucial DMs in every environmental and non-environmental conflict. In the first step, a GMCR approach is applied to resolve a potential dispute among traditional DMs. These DMs include stakeholders who 'are in control of options or courses of action he or she has at his disposal (Xu *et al.* 2018)'. Every conventional GMCR has five steps: determining DMs, specifying their options, finding feasible states, determining allowable state transitions, and finding individual stabilities. After these steps, a common GMCR ends by finding the most stable state using four stability equilibria. These stability equilibria are Nash, sequential stability (SEQ), general metarationality (GMR), and symmetric metarationality (SMR).

However, the proposed methodology will be continued by adopting a GA method to optimize the results obtained from the GMCR approach. This optimization will result in outcomes that are modified according to the most critical environmental demands. GA operators include selection, crossover, and mutation. These operators will be utilized to optimize the obtained resolution for GMCR.

The proposed methodology in this paper is illustrated in Figure 1. This method has been applied to a real-life case study to evaluate its performance. This case study and its characteristics are presented in Subsection 3.2.

3.2. A real-life case study

Briefly, Talaab-e Jazmurian (or hamun-e Jazmurian) or TJ is an endangered seasonal lake located in a topographical-low basin in southeast Iran (Rashki *et al.* 2017). Jazmurian is the seventh-largest lake in Iran, and its water capacity reaches 1860.72 MCM in wet years.

This region is a topographic-low basin that lies between longitudes 58°40′ to 59°14′ and latitudes 27°10′ to 27°41′. The Jazmurian seasonal lake covers an area of about 5,500 km^2, and its altitude above sea level varies from 4,359 m (the highest elevation) to 363 m (the lowest elevation). Temperatures, similarly, vary from 50° centigrade in summer to −14° centigrade in winter. The mean annual precipitation is 360.6 mm in the wettest regions and 69.1 mm in the driest areas. Consequently, the studied area has dry climatic conditions with hot summers and cold winters (Booklet of Jazmurian Lake Watershed Basic Studies, P 9–22, June–July 2020).

Jazmurian's survival is vital for the region's ecosystem; however, this seasonal lake has witnessed a considerable decline in water level in recent years (Vaezi *et al.* 2019). Figure 2 shows the geographical position and catchment area of the Jazmurian lake in Iran's map.

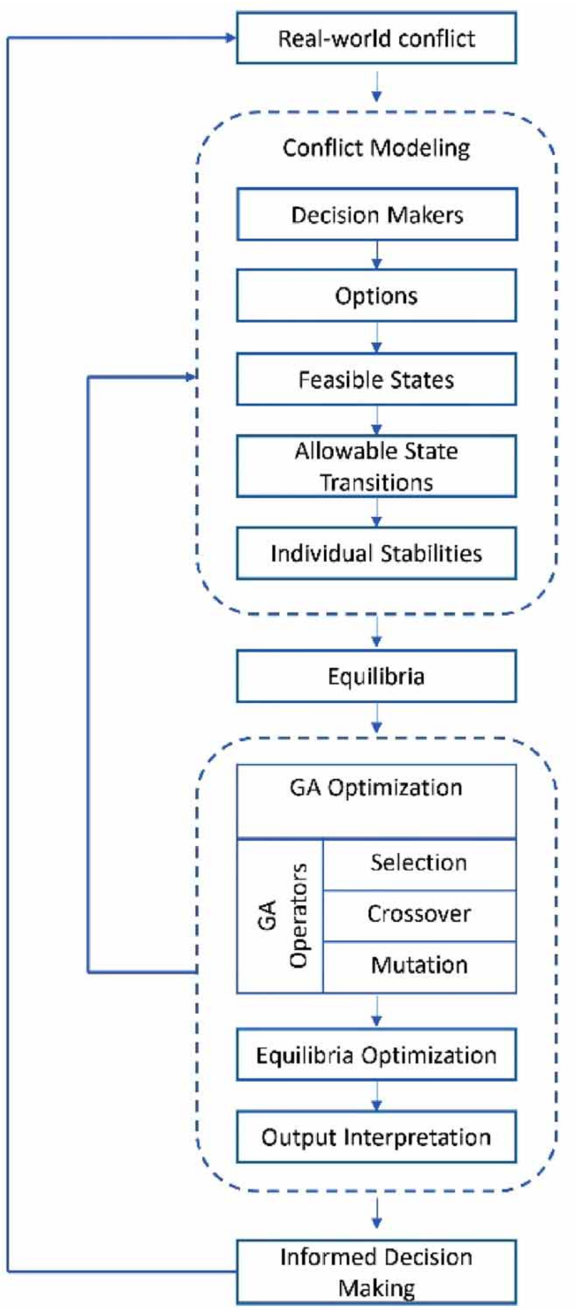

Figure 1 | Overall framework for the proposed method (modified from Hipel & Fang (2020) and Huang *et al.* (2020)).

The long-term drought, decreasing annual precipitation (Jalalkamali *et al.* 2011), rapid evaporation rate, water overuse and misuse, inappropriate water transmission, and lack of wastewater management are the leading factors gradually contributing to this seasonal lake destruction (Alizadeh-Choobari *et al.* 2014; Rezaei *et al.* 2019).

Therefore, there is intensified and inevitable competition over scarce water resources in the region resulting in a dramatic increase in water-related crises, controversies, and conflicts (Zakeri *et al.* 2022). Accordingly, this research effort tries to address a serious dispute over the allocation of water resources of the Jazmurian lake.

Figure 3 demonstrates the total amount of annual inflow and outflow of the Jazmurian lake. According to this figure, there is a water deficit equal to 395.57 MCM.

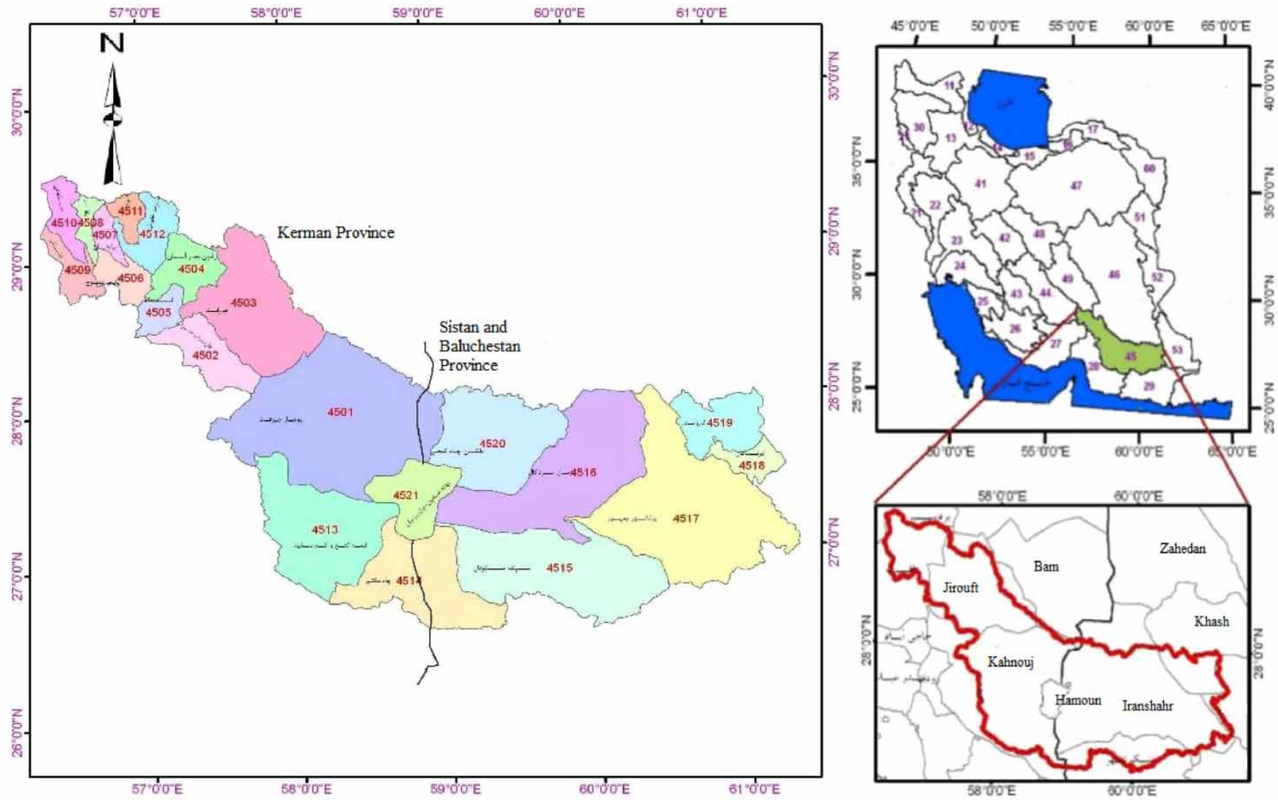

Figure 2 | Geographical position and catchment area of the Jazmurian lake (Booklet of Jazmurian Lake Watershed Basic Studies, P 10, June–July 2020).

4. RESULTS

4.1. GMCR results

Every GMCR approach requires the determination of DMs, a comprehensive analysis, and possible states of a given conflict. Moreover, state transitions and each DM's preferences should also be specified (Gopalakrishnan *et al.* 2005; Xu *et al.* 2018). After clarifying and ranking each DM's preferences, equilibrium solutions can be obtained (Xu *et al.* 2018). A state is stable from a DM's perspectives if that DM chooses not to depart from that state (Gopalakrishnan *et al.* 2005; Xu *et al.* 2018). From all DMs' perspectives, a stable state is an equilibrium and also forms a possible solution for the conflict. States' stability can be determined using definitions of Nash, SEQ, GMR, and SMR stability (Xu *et al.* 2018).

TJ's conflict has two key DMs: the government and the local community. Although environmentalists are among the involved groups, their contradictory demands have made it difficult to reach a consensus. The government sector claims the right of ownership over the majority of water amount, and they utilize this right by constructing dams and initializing water transfer projects. However, a national agreement enforces the government to allocate appropriate water share to other stakeholders, including farmers and herders, the primary source of livelihood in this region. Despite their allegation, the government sector is reluctant to release the local community's water share, and this reluctance has resulted in a long-term conflict. This conflict can be modeled by the GMCR as follows:

There are two DMs and four options, three options for the government sector and one for the local community.

The government's options consist of neglect and continue (ignoring the local community's demands and following previous procedures in water allocation), give up and accept (giving up dam construction and water transfer projects, and accepting the local community's right of ownership, instead of having a specific water share), and modify (modify the current agreement to satisfy local community's demands).

The local community's options include: insist (insisting on their water share right).

DMs and their options are shown in Table 1.

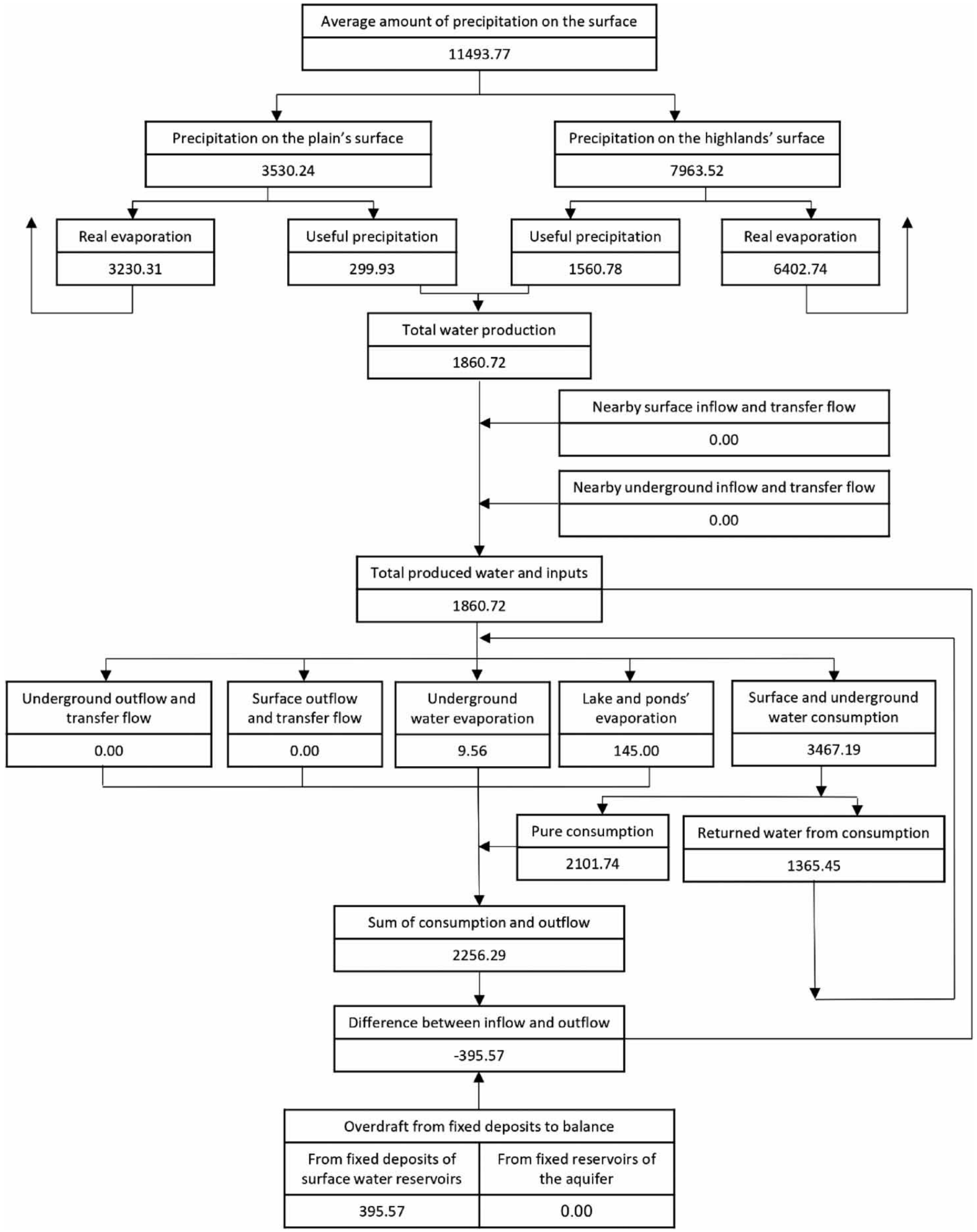

Figure 3 | The total amount of annual inflow and outflow of the Jazmurian lake. All figures are in a million cubic meters or MCM (Iranian Department of Environment 2020).

Table 1 | Decision-makers and their options in the Jazmurian lake conflict

DM	Option	Description
The government sector	• Neglect and continue • Give up and accept • Modify	• Continue current policy without releasing local community's water share • Leave dam construction and accept the local community's legal right • Modify the current agreement to satisfy both its and local community's demands
The local community	• Insist	• Insist on their demand's satisfaction

Accordingly, the total number of possible states is 16; among them, ten options are infeasible for some reasons, and other feasible states are listed in Table 2.

In this table, a 'Y' symbol means selecting this option by the empowered DM, while 'N' indicates not selecting this option by controlling DM.

After determining the DMs' feasible states, these states are prioritized based on collected information and experts' opinions along with conflict root causes' studies (Shahbaznezhadfard *et al.* 2021). Table 3 shows states' ranking from the DMs' point of view.

The integrated graph model of TJ conflict is depicted in Figure 4 in which the dotted arrows stand for the local community and the continuous arrows indicate the government sector state transition.

The states' stability by utilizing four well-known stability definitions is analyzed in the next step where four solution concepts, Nash, SEQ, GMR, and SMR, are used. Each of these definitions is based on specific behavioral patterns and will produce distinctive equilibria (Xu *et al.* 2018). To be more precise and faster, the GMCR + software program is used instead of manual analysis. The results are shown in Table 4.

Table 2 | Feasible states in the Jazmurian lake conflict

DM	Option	Feasible States					
The government sector	• Neglect and continue	Y	Y	N	N	N	N
	• Give up and accept	N	N	Y	Y	N	N
	• Modify	N	N	N	N	Y	Y
The local community	• Insist	N	Y	N	Y	N	Y
Label		1	2	3	4	5	6

Table 3 | State ranking for DMs in the Jazmurian lake conflict

	States					
Decision-makers	Most preferred			Least preferred		
The government sector	5	1	3	6	2	4
The local community	5	3	6	4	2	1

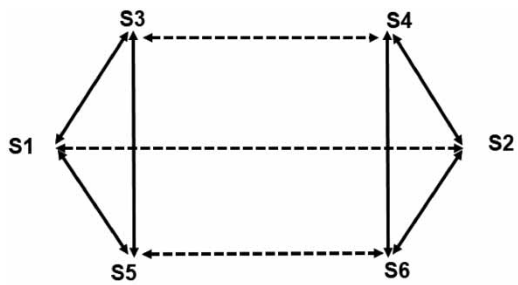

Figure 4 | Integrated graph model for the Jazmurian lake conflict.

Table 4 | Resulting outcomes of the Jazmurian lake conflict

	States					
Stability definition	S_1	S_2	S_3	S_4	S_5	S_6
Nash					*	
GMR			*		*	
SMR			*		*	
SEQ		*			*	

According to Table 4, state 5 – i.e. modifying the current agreement to satisfy both governmental and local demands – is the most stable state and a possible resolution of the conflict.

4.2. Sensitivity analysis

This kind of analysis is specifically advantageous when meaningful changes in certain model parameters can considerably change the robustness and stability of the model. High degrees of uncertainty necessitate sensitivity analysis to be implemented (Philpot *et al.* 2016; Xu *et al.* 2018).

In developing the initial model of the Jazmurian lake conflict, the primary stakeholders have been considered according to the field studies and experts' opinions. Therefore, it is decided that the environmental groups (governmental and non-governmental) be excluded from the key DMs. Although the determining roles of these groups are undeniable, their interests are so contradictory that they make it impossible to find a clear preference among them. This is because the environmental governmental organizations are represented by the agricultural sectors and their preferences are similar. On the other hand, non-governmental environmental organizations are of different preferences and also do not have operational power to exert their decisions.

However, if these groups change their current status and try to alter the preferences, their existence might influence the final solution. Therefore, in an alternative scenario, these groups (i.e. environmental governmental and non-governmental organizations) have been considered as the primary DMs. The results are shown in Table 5.

The total number of states is $2^8 = 256$, among which 48 are feasible. Other states cannot happen since there are conflicting states, impossible to happen simultaneously. The most desirable state for the governmental sector will occur when other DMs abandon their water share or accept an agreement that satisfies all sectors' water shares. On the other hand, the least favorable situation for the government is the state in which other sectors insist on their maximum water share, so the government sector should give up on their demands. Similarly, other sectors' most and least desirable states can be determined. Using the four stability equations, the most stable state for all four DMs will occur when all sectors agree to modify the current

Table 5 | Examination of various scenarios of DMs and their options for the sensitivity analysis process

DM	Option	Description
The government sector	• Neglect and continue • Give up and accept • Modify	• Continue current policy without releasing local community's water share • Leave dam construction and accept the local community's legal right • Modify the current agreement to satisfy both its and local community's demands
The local community	• Insist	• Insist on their demand's satisfaction
Department of Environment (governmental organization)	• Restrict other sectors' watershare • Accept an agreement	• Restrict and limit other sectors' watershare to increase the lake's watershare • Try to reach an agreement with other involved sectors
Environmental NGOs	• Eliminate other sectors' watershare • Accept an agreement	• Totally eliminate other sectors' watershare to increase natural environment share as much as possible • Accept an agreement in which all sectors' demand can be satisfied

agreement and find a solution to satisfy all sectors' demands. Therefore, it is conceivable that the final solution for four DMs is the same as the final solution for two stakeholders. Consequently, it can be concluded that considering more DMs cannot considerably change the final results of the GMCR model for water share conflict in the Jazmurian lake.

However, if DM preferences have been altered and modified, the results will be significantly different. For instance, if non-governmental organizations do not have the power to exert their demands, governmental organizations (the government sector and the Department of Environment) are capable of eliminating this sector and ignoring its preferences. Accordingly, the results of the GMCR method are highly sensitive to the DMs' preferences. If preferences are changed, the most stable state will be changed regarding modified preferences. Nevertheless, if the DMs are changed, the final results' changes will be negligible.

4.3. GA optimization results

Before proceeding to the next level of classic GMCR and accepting the achieved resolutions as the most stable ones, it is necessary to reconsider the preliminary list of DMs and determine the position of 'the natural environment' as a critical DM. According to Karamouz *et al.* (2014), water allocation to agricultural demands (agricultural sector), hydropower demands (governmental sector), and ecosystem demands (environmental sector) are conflicting and competing objectives in a potential water reservoir. Consequently, the current DMs and their options do not satisfy severe environmental concerns in this region since they are based on agricultural and industrial demands. Therefore, the next step of the proposed method is to incorporate environmental requirements into the obtained results to fulfill the natural environment's demands.

Owing to the fact that the process of decision-making is highly subjective and to avoid biased preferences, the environmental demands will be measured through a logical frame (Maier *et al.* 2014). Thus, decision-making approaches and EAs can assist DMs in finding the most appropriate preferences for the natural environment DM.

The objective function considered in this study is the minimization of squared deficit from demand (Srinivasa Raju & Nagesh Kumar 2004; Ahmed & Sarma 2005; Kumar *et al.* 2006; Simpson & Elhay 2008), which is given below:

$$\text{Formula 1:Minimize:Objective Function} = \sum_{t=1}^{12} (R_t - D_t)^2 + \sum_{t=1}^{12} (S_t - S_{t+1} + I_t - R_t - E_t)^2$$

where t is the time period in month of a year, R_t is the water release in the time period t, D_t is the maximum non-ecological demand, S_t is the reservoir storage in month t, I_t is the incoming flow to the reservoir, and E_t is the evaporation rate in month t.

Table 5 shows the data that have been used to optimize the results obtained by the GMCR application (Table 4). This data have been extracted from the Ministry of Water and Waste Water database. Values are in million cubic meters (MCM) except for E_t which is presented in millimeters. The data used in GA optimization procedure are displayed in Table 6.

Population size in this research equals to 50 and S_t for the month of April is 414.2. Other months' S_t can be achieved by Formula 2:

$$\text{Formula 2: } S_{t+1} = S_t + I_t - R_t - E_t$$

In the above formula (Formula 2), S_{t+1} is the reservoir storage in month $t+1$, while other variables are the same as Formula 1.

Table 6 | Data used in GA optimization (Graduate University of Advanced Technology and Industry 2019)

	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
I_t	50.02	23.29	11.29	10.46	11.16	9.51	11.05	10.45	10.8	18.75	31.42	48.82
E_t	528	736	894	942	880	734	526	350	224	172	222	328
S_t	414.2	427.3	337.919	251.69	180.84	102.7	49.73	18.27	11.8	9.2	7.69	14.97
R_t	15.8	10.19	11.8	16.3	15.4	8.4	4.8	2.5	0.009	1.6	7.1	10.2

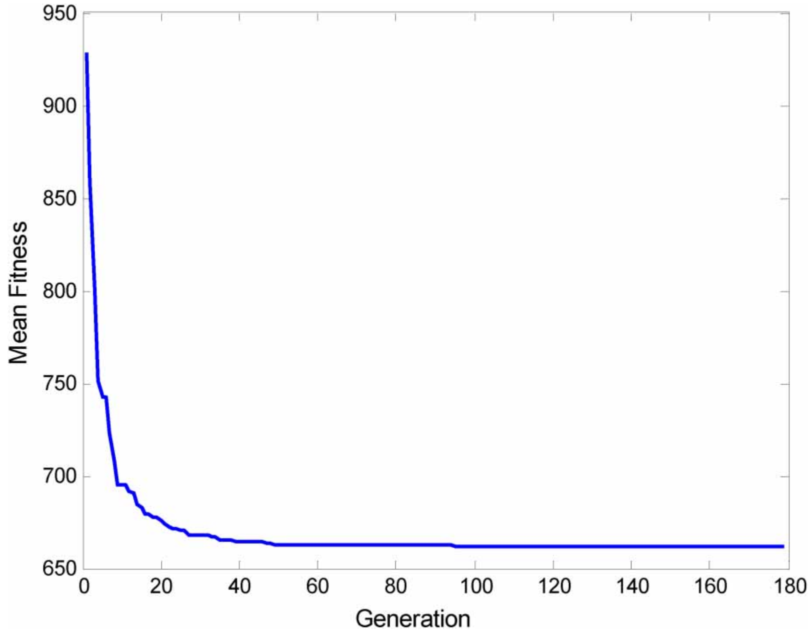

Figure 5 | GA optimization outcomes.

Reservoir storage and release constraint are given below, respectively.

Formula 3: $S_{\min} \le S_t \le S_{\max}, \quad 0 \le S_t \le 510$

Formula 4: $0 \le R_t$

Formula 3 means that the maximum storage of the reservoir cannot violate the maximum capacity and the minimum reservoir should remain above zero. Formula 4, on the other hand, emphasizes that the release amount of the reservoir should not be equal to zero. Other variables have been adjusted according to GA's default settings.

The outcomes of this objective function determine the water requirement of the reservoir to survive. In fact, when the conflicting parties try to reach an agreement by modifying the current legislation and determine new water share, they should allocate the specified water amount to the natural environment to avoid disastrous environmental harm. The obtained results are shown in Figure 5.

GA outcomes are comparable in amount with the reservoir's demand to survive stated in environmental research (Department of Environment 2020). Results show that the GA if applied can optimize the solutions resulting from GMCR. This will contribute to more environmental-friendly solutions. Table 7 summarizes the GA optimization results.

4.4. GA sensitivity analysis

The sensitivity analysis results are shown in Figure 6. According to this figure, the results of the GA optimization will not be affected by changing the variable 'R' in a particular domain. The specific domain has been determined by studying the water release long-term patterns in the Jazmurian lake. These patterns show that the typical water release domain is approximately 10% lower or higher than the usual water amount. By changing the variable 'R' in the mentioned domain, the variable 'S' changes are meager and negligible. Therefore, it is justifiable to rely on the obtained results of the GA. Figure 6 and Table 8 demonstrate the GA sensitivity analysis outcomes.

Table 7 | The results obtained from the GA optimization based on the generation

Gen.	1	20	40	60	80	100	120	140	160	180
Result	928.3	676.1	664.8	662.7	662.4	662.2	662.2	662.2	662.2	662.2

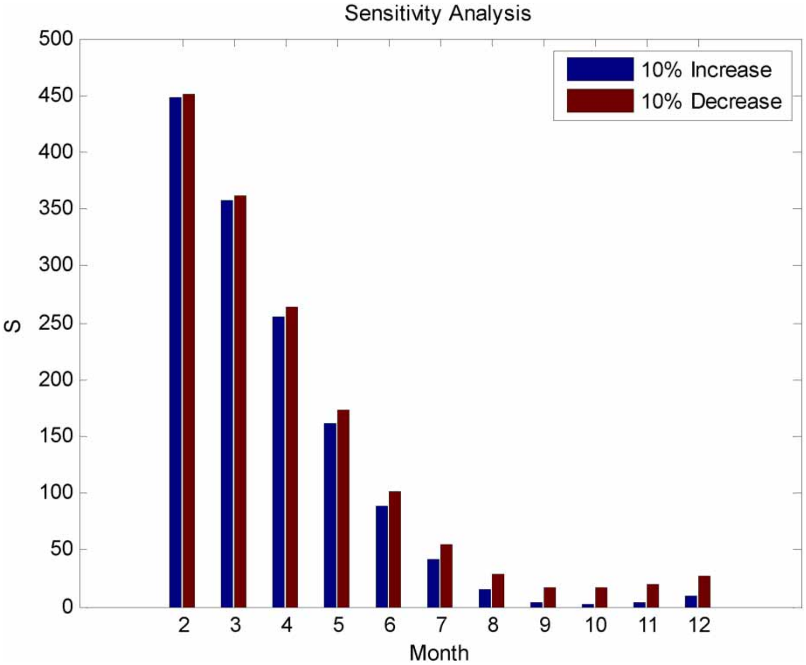

Figure 6 | The genetic algorithm sensitivity analysis.

Table 8 | The results obtained from the GA sensitivity analysis based on months

	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
10%de	450.52	361.75	263.31	172.63	101.19	55.33	28.54	16.94	17.10	19.93	26.77
10%in	448.48	357.34	255.64	161.87	88.75	41.94	14.66	3.06	2.90	4.31	9.11

5. DISCUSSION

The present research tries to incorporate GA into GMCR to improve the environmental performance of GMCR. The concept of considering the natural environment as a distinctive stakeholder has roots in a study conducted by Hammond & Booth (2010); thereby, the natural environment's primary demands can be considered. Although GMCR has been successfully applied in numerous environmental-related conflicts, the natural environment has not been considered an independent DM. For instance, in a water allocation conflict in Hawaii conducted by Gopalakrishnan *et al.* (2005), the stakeholders are the local community, business owners, and the water commission that may not necessarily be the true representatives of the natural environment. In fact, the water commission, the responsible organization for water share specification, is concerned about environmental requirements. However, it has organizational responsibilities making it impossible to consider all environmental aspects of a conflict. Similarly, other environmental conflicts do not include the natural environment as the primary DM. The following papers are some of these research studies:

- Madani & Hipel (2007) considered neighboring countries as involved parties in a water allocation conflict over the Jordan river.
- In a 2014 study, Zanjanian *et al.* specified four DMs, including an agriculture organization, the water and wastewater company, the water authority company, and the Department of Environment. The Department of Environment is a governmental organization combining governmental and environmental interests while determining preferences.
- In Philpot *et al.*'s (2016) study, DMs are local communities and official organizations.
- Taravatrooy *et al.* (2019) considered three governmental organizations as primary DMs in a fuzzy-based conflict resolution.
- Another water allocation conflict in China considered three neighboring provinces and a governmental organization as the main DMs (Yu *et al.* 2019).

- In a recent study conducted by Shahbaznezhadfard *et al.* (2021), the interactions between humans and the natural environment have been considered to enhance GMCR performance in a water allocation conflict. The proposed method for considering these relations has been the system dynamic approach. However, the natural environment has not been considered an independent DM.

It seems that environmental preferences are included in the decision-making process by governmental and official sectors with partial inclinations to the governmental sectors. Therefore, considering the natural environment as an independent stakeholder is crucial, as it is considered in the current study.

The present research case study is an endangered seasonal lake with conflicting demands of stakeholders. The GMCR approach has been conveniently applied to several previous studies about water allocation and water-related conflicts to obtain sustainable resolution. In trying to conserve the Hoor Al-Azim wetland, Pournabi *et al.* (2021) found that the involved organizations' strategies should be changed considerably. Dowlatabadi *et al.* (2020) have also emphasized the role of agreement between conflicting groups as the final resolution for a transboundary wetland conflict between Iran, Turkey, and Iraq. The case study of Elmira groundwater contamination is the main focus of Xu *et al.*'s (2018) book, and the final solution achieved by GMCR is to modify the current agreement between involved parties. Accordingly, the present study's final result of modifying the current agreement is in compliance with several water-related conflicts.

GA has also been used in several water allocation optimization problems. The current study's objective function has been evolved from similar studies and is adopted to minimize the water outflow from the Jazmurian basin to conserve the lake.

According to the most reliable studies regarding Jazmurian lake's water demand, the pure water demand of industrial and agricultural sectors equals 1,019.8 MCM. On the other hand, the water supply of the Jazmurian basin is 11,493.77 MCM, and the water outflow equals 2,256.29 MCM. Consequently, there is about a 395.57 MCM water deficit (Figure 3). The results of GA optimization (Figure 5) demonstrate that for saving the Jazmurian lake, the water outflow should be about 650 MCM. If the water outflow decreases by 650 MCM, there will be about 369 MCM of surplus water amount. This extra water reservation can save the Jazmurian seasonal lake. However, these results can be further improved by determining the actual demand of agricultural and industrial sectors since the lake's survival should not result in other sectors' demise.

Briefly, with the lack of data taken into account, the results of incorporating the GA approach into the GMCR paradigm indicate that the resolutions proposed by GMCR can be optimized to satisfy 'the natural environment' demands. It should also be clarified that the results of this research effort can be extended to any potential conflict regardless of being environmental or not, since 'the natural environment' can be affected by any decision reached by given controversial DMs.

6. CONCLUSIONS

This research effort presents a new methodology to modify and improve DMs' concept in the well-known GMCR, considering the necessity of incorporating 'the natural environment' as an inseparable stakeholder in every given conflict regardless of being environmental or not. Although 'the natural environment' is a potential stakeholder and DM of any conflict, it is not considered as one of the main stakeholders in the conventional GMCR in general since 'the natural environment' does not have the power to make decisions and enforce other parties to follow its preferences. Therefore, there is a need to find a way to incorporate 'the natural environment' demands to resolve various conflicts in a sustainable manner. Researchers hope that the proposed methodology can maximize the environmental benefits and minimize the adverse environmental impacts. To evaluate the applicability and efficiency of the proposed methodology, it is applied to a real-world water resource-related conflict in Iran. The results show that a modified definition of DMs might improve the environmental efficiency of GMCR's solutions. The main conclusions of this study are as follows:

- Although GMCR is a robust approach to addressing environmental or non-environmental conflicts, its definition of stakeholders excludes the natural environment as a critical stakeholder. The present study tries to compensate for this ignorance.
- Even though environmental sectors might have been among the potential stakeholders of a conflict, their preferences might be partial and subjective since humans are exposed to deliberate or unintended flawed decision-making.
- Natural environment is not a concrete and specified entity; therefore, an optimization method can be used to optimize the results of a GMCR approach to satisfy environmental demands.
- GA is an efficient optimization method that has been widely applied in several optimization problems, and it can be useful to optimize the results of GMCR.

- Since the results of GMCR are rarely quantified, the results should be converted into measurable figures that can be optimized by the GA method.
- A real-life case study is to conserve an endangered seasonal lake whose water has been allocated to several stakeholders. After conducting the GMCR approach, its results have been optimized by a GA method.
- The results might be the most optimal solutions for the lake's survival without destroying other involved sectors' water share.

In future studies, other approaches like System Dynamics (SD), Agent-Based Models, and Game Theory can be used to enhance the results of the GMCR method. Other conflicts, specifically non-environmental disputes, should be considered in future studies to evaluate the performance of the proposed method. Finally, the quantification of GMCR results should be accurately formulated to make the results more reliable.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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