Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 6, June, 2018

A Game Theory Approach for Conjunctive Use Optimization Model Based on Virtual Water Concept

Abbas Sedghamiz [a], Manouchehr Heidarpour [a], Mohammad Reza Nikoo [b*], Saeed Eslamian [a]

[a] *Darab School of Agriculture and Natural Resources, Shiraz University, Shiraz, Iran.*

[b] *School of Engineering, Department of Civil and Environmental Engineering, Shiraz University, Shiraz, Iran.*

Received 19 December 2017; Accepted 02 June 2018

Abstract

In this study to allocate the agricultural and environmental water, considering virtual water concept, a multi-objective optimization model based on NSGA-II is developed. The objectives consist of equity maximization, agricultural benefit maximization for each region, maximization of green water utilization and finally minimization of environmental shortage. Then a cooperative game (Grand Coalition) model is presented by forming all possible coalitions. By the game model including Nucleolus, Proportional Nucleolus, Normal Nucleolus and Shapley methods, the benefit is reallocated based on all Pareto optimal solutions obtained from multi-objective optimization model. Then using two famous fallback bargaining methods, Unanimity and q-Approval, preferable alternative (solution) for each of the cooperative games is determined. Finally, based on the obtained benefit for each selected alternatives, the two most beneficial alternatives are chosen. The proposed methodology applied for water allocation of Minoo-Dasht, Azad-Shahr and Gonbad-Kavoos cities in Golestan province, Iran for a 3-year period as a case study. Also, eight crops including Wheat, Alfalfa, Barley, Bean, Rice, Corn, Soya, and Cotton are selected based on local experts' recommendations. The models' results indicated no significant difference between the grand coalition model and the multi-objective optimization model in terms of the average cultivation area (a relative change of 2.1%), while lower agricultural water allocation occurred for the grand coalition model (about 10.35 percent average) compared with the multi-objective optimization model. It is also observed that more agricultural benefit gained by the grand coalition model (32 percent average). Finally, it is found that Wheat and Corn hold the most rates of import and export, respectively, and Rice was the crop which has the least shortage of production to supply food demand.

Keywords: Agricultural and Environmental Water Allocation; Multi-Objective Optimization Model; Fallback Bargaining Methods; Virtual Water; Cooperative Games Model.

1. Introduction

In many countries, agricultural activities and food production are in critical condition due to water [1-2] and low irrigation efficiency [3] As a remedy, virtual water concept can be used to alleviate water scarcity and enhance water use efficiency [4-6]. Virtual water concept was first used by Allan [7] to support the idea that in water scarcity condition, water can be saved for municipal needs by importing more food (i.e. virtual water) instead of producing food [8-10]. In another study, Li et al. [11] confirmed that virtual water trading can save excess water without any significant changes in revenue obtained in a non-trading activity. Also, taking the role of water price into account, Fracasso et al. [12] proved that higher water irrigation prices, reduce virtual water exports. Noticeably, Liu et al. [13] suggested that future actions should be focused on extending self-sufficiency through more efficient processes.

* Corresponding author: nikoo@shirazu.ac.ir

http://dx.doi.org/10.28991/cej-0309175

Practicing conjunctive use of surface and groundwater is an efficient way to produce more food, because it would cause more areas to be planted [14]. In this field, a variety of studies have been reported so far [15-20].

Participants of the agricultural districts with common water resources often experience conflicts. As an efficient tool, game theory can incorporate interaction and conflict between participants and has been used by many water resource researchers, recently [21-25]. One of the main branches of this theory consists of the cooperative game methods [26-29].The studies which consist of a multi-objective optimization problem may have more than one solution, depending on the applied solution method [30-31]. In case, to select the best-obtained solution, Nikoo et al. [32] applied Unanimity Fallback Bargaining (UFB) method to find the best agreed-upon design point on the trade-off curve.

In this paper, by focusing on virtual water concept, a conjunctive use model is developed to optimize water allocation to different agriculture sectors. The methodology includes a multi-objective optimization (M. O.) model which is followed by a game theory (grand coalition) model. The M. O. model's objectives are green water rate maximization, equity maximization, environmental shortage minimization and benefit maximization. Unlike the mentioned studies on the conjunctive use, virtual water concept and game theory approach are taken into consideration simultaneously as a key factor in this study. Maximization of green to total water ratio as one of the objectives can lead to choose crops with greater yield and more water use efficiency. Also, this will result in a set of Pareto optimal solution points (solution) with less water allocation and more productivity through running the M. O. model. After forming all possible coalitions, the cooperative benefit of the grand coalition is calculated. Subsequently, different cooperative game methods such as Nucleolus, Proportional Nucleolus, Normal Nucleolus and Shapley methods, are applied to reallocate the benefit between the regions. Then the most preferable alternatives are selected for each cooperative game method, based on Fallback Bargaining methods, i.e., Unanimity (UFB) and q-Approval (q-Approval FB). Finally, the two most profitable alternatives are chosen as the most acceptable alternatives.

This innovative methodology can lead to save water in two steps. In the first step, when the M. O. model is applied through green water rate maximization and in the second step, when the grand coalition model is applied. The agricultural benefit is also increased in the same procedure, through benefit maximization in both the M. O. model and the grand coalition model.

2. Methodology

2.1. NSGA-II Multi-Objective Optimization Model

Non-Dominant Sorting Genetic Algorithm (NSGA-II) was firstly proposed by Deb et al. [33] to solve multi-objective optimization problem and has been used by many researchers so far [23, 32, 34, 35]. In this type of problems, there is no single optimal solution since there could be various conflicts between objectives. In fact, the optimal solutions, which are called "Pareto-Optimal Solutions", are superior to all other solutions in the search space [36, 37].

Figure 1 illustrates the framework of the developed model which includes four sequential parts. Required data is collected in the first step. In the second step, the M. O. model calculates both the optimum amount of the agricultural area for different crops in each region and total allocated conjunctive water recourses. The M. O. model is formed by six objectives including equity maximization, benefit maximization for each region, green water usage maximization and finally environmental shortage minimization. The constraints of this optimization model are cultivable area, self-sufficiency, and allowable groundwater extraction. In the third step, after forming the possible coalitions, their related benefit determined by reallocating the amount of water which is allocated by the M. O. model. Then, the agricultural benefit is reallocated to the regions of the study area for all Pareto-optimal solutions (points) on the trade-off curve by use of different cooperative games. Finally, in the last step two most preferable alternatives are chosen by applying two Fallback Bargaining (FB) methods. The formulation of the M. O. model is as follows:

$$\text{Min } f_1 = \left[\frac{\sum_{r=1}^{m}\left(\frac{Gal_r/P_{sgr} + Sal_r/P_{sgr} - W_{sg}/P_{sg}}{W_{sg}/P_{sg}}\right)^2}{m-1}\right]^{1/2} \tag{1}$$

$$\text{Max } f_2 = \sum_{y=1}^{Ny}\sum_{t=1}^{2}\sum_{c=1}^{n}\left(x_{ytc}.Y_{ytc}.P'_{ytc} - x_{ytc}.C_{ytc} - vt_{ytc}\right) \quad \text{for Minoo} - \text{Dasht} \tag{2}$$

$$\text{Max } f_3 = \sum_{y=1}^{Ny}\sum_{t=1}^{2}\sum_{c=1}^{n}\left(x_{ytc}.Y_{ytc}.P'_{ytc} - x_{ytc}.C_{ytc} - vt_{ytc}\right) \quad \text{for Azad} - \text{Shahr} \tag{3}$$

$$\text{Max } f_4 = \sum_{y=1}^{Ny}\sum_{t=1}^{2}\sum_{c=1}^{n}\left(x_{ytc}.Y_{ytc}.P'_{ytc} - x_{ytc}.C_{ytc} - vt_{ytc}\right) \quad \text{for Gonbad} - \text{Kavoos} \tag{4}$$

$$\text{Max } f_5 = \frac{\sum_{r=1}^{nr}\sum_{y=1}^{Nr}\sum_{t=1}^{2}\sum_{c=1}^{n} x_{rytc}.Y_{rytc}.VWC_{g-rytc}}{\sum_{r=1}^{nr}\sum_{y=1}^{Nr}\sum_{t=1}^{2}\sum_{c=1}^{n} x_{rytc}.Y_{rytc}.VWC_{rytc}} \tag{5}$$

$$\text{Min } f_6 = \sum_{y=1}^{Nr}\sum_{i=1}^{12}\sum_{river=1}^{nr}\left(E_{req.} - E_{all.}\right)^2 \tag{6}$$

Subject to:

$$al_{sgr} = \sum_{y=1}^{Nr}\sum_{t=1}^{2}\sum_{c=1}^{n}\sum_{r=1}^{m} x_{ytcr}.\frac{(ET - Re)_{ytcr}}{eff.} \tag{7}$$

$$Gal_{sgr} = \left(D_{sgr} + I_{sgr} + Garden_{sgr} + E_{all} + al_{sgr}\right) - Sal_{sgr} \tag{8}$$

$$W_{sg} = \sum_{r=1}^{m}(Gal_{sgr} + Sal_{sgr}) \tag{9}$$

$$x_{rc}.Y_{rc} + vt_c \geq P_{sgr}.D_c \tag{10}$$

$$\sum_{c=1}^{n} x_{rc} \leq Ar_{sgr} \tag{11}$$

$$Gal_{sgr} \leq GW_{allowable} \tag{12}$$

Where:

Gal, Sal, W = Groundwater, river and total water allocation (MCM), respectively.

$GW_{allowable}$ = Allowable groundwater extraction (MCM).

x, Y, P', C = Area (ha), yield (ton/ha), price ($/ton) and cost ($/ton) for each crop respectively.

VWC, vt = Virtual water content (m^3/ton) and virtual trade ($), respectively.

E_{req}, E_{all} = Environmental demand (MCM) and river flow allocation (MCM), respectively.

ET, Re = Evapotranspiration (mm) and effective precipitation (mm), respectively.

D, I = Drinking and industrial water demand (MCM), respectively.

Garden, al = Horticultural and agricultural water demand (MCM), respectively.

Dc, P = Crop demand per capita (ton/person) and population, respectively.

Ar = Maximum cultivation area in each region (ha).

y, t, c, river = Index for year, crop season, crop type and river, respectively.

r, s, g = Index for region, surface water and groundwater, respectively.

eff. = Irrigation efficiency (0.6).

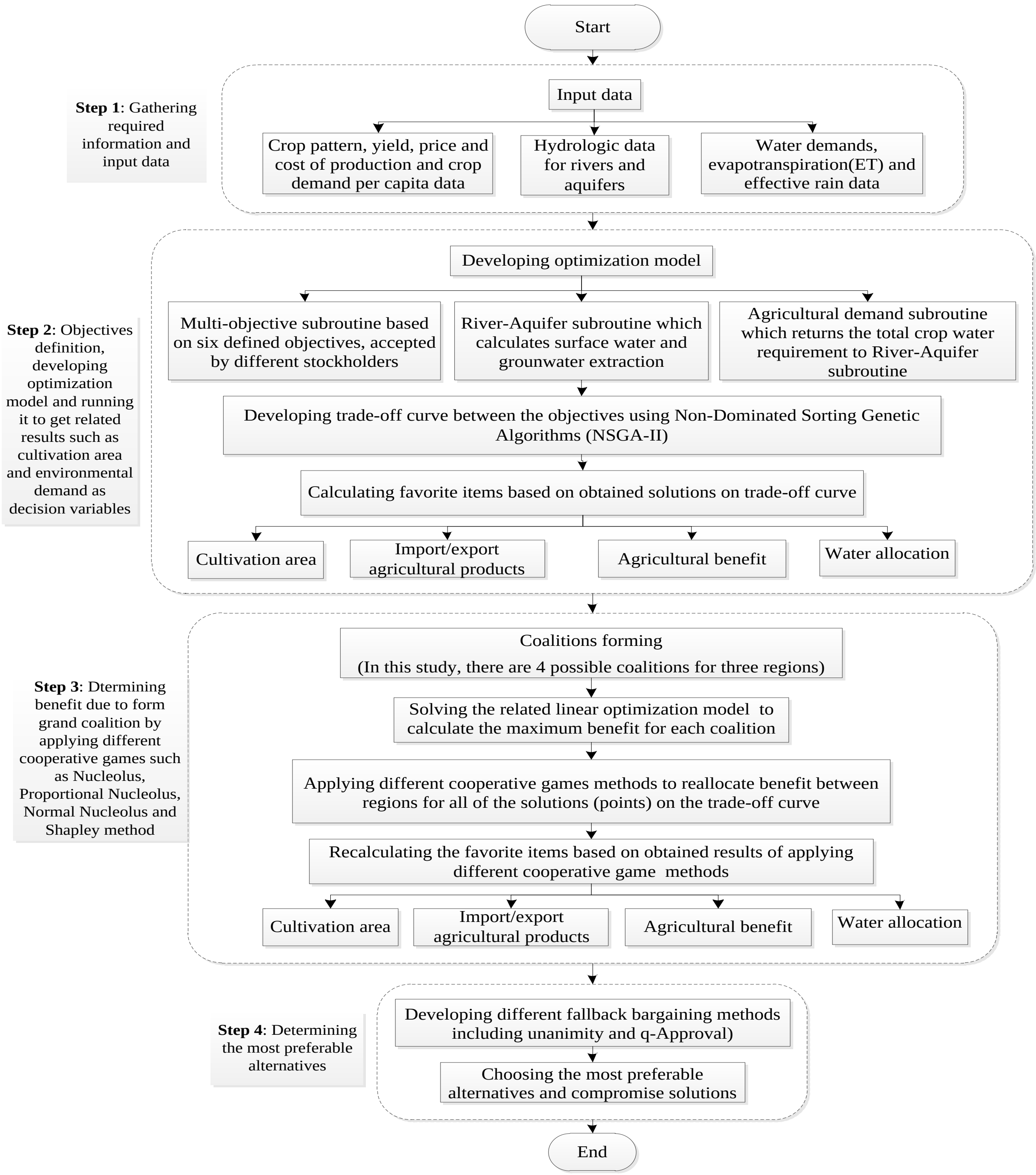

Figure 1. The framework of the developed conjunctive use optimization model based on virtual water concept and game theory approach

2.2. Cooperative Game Theory Methods

Game theory as a powerful tool in decision making has been used in different fields of sciences including economics, social science, engineering, agriculture etc. In this study, after running the multi-objective optimization model, the possible coalitions are formed and the agricultural benefit for each region in the study area is reallocated by applying different cooperative game theory methods including Nucleolus, Proportional Nucleolus, Normal Nucleolus and Shapley Value [25-27, 34, 38-42].

2.3. Fallback Bargaining (FB) Method

By solving a multi-objective problem, a variety of solutions (alternatives) could be obtained. Hence, it is of great importance to choose the most preferable solutions. To do this, the Fallback Bargaining Method as a very popular method in water resources management which is applied by different researchers [32, 35, 43] is used. In this research, two specific branches of this method i.e. Unanimity Fallback Bargaining (UFB) and q-Approval Fallback Bargaining (q-Approval FB) [44] are applied.

2.4. Study Area

To examine the efficiency of the proposed methodology, the available data from a specific part of Golestan province in Iran which consists of three regions, i.e. Minoo-Dasht, Azad-Shahr and Gonbad-Kavoos are used (Figure 2). The annual precipitation mostly occurs from January to April in higher lands of the region. Its rate is between 300 and 1000 millimeter annually. In contrast, the potential evapotranspiration ranges from 800 mm in the mountains to more than 1200 mm in areas with lower altitude [45]. In the research, two planting seasons (i.e. winter and summer) are considered. In winter three crops, including wheat, barley, bean and in summer season four other crops, including rice, corn, soya and cotton, in addition to alfalfa as a perennial crop were selected as the most desirable crops.

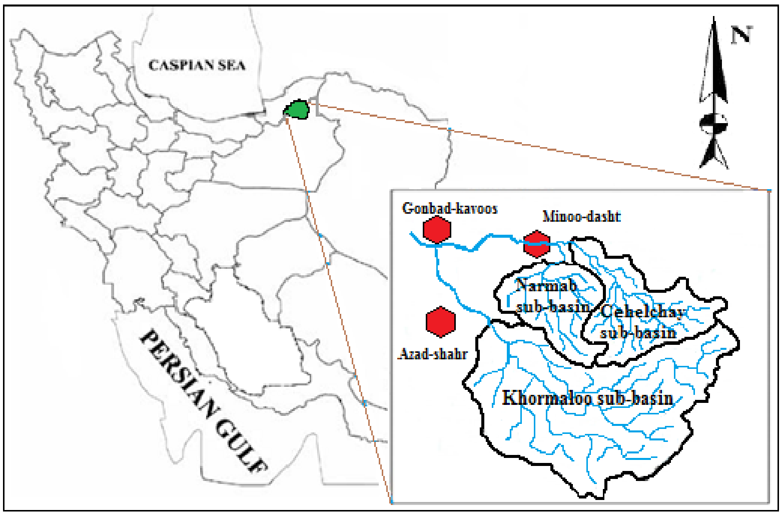

Figure 2. The location of the study area in Iran

3. Results and Discussion

According to Figure 1, after gathering data, the NSGA-II multi-objective optimization model is developed. The model has 200 decision variables including cultivation area and environmental river flows as the decision variables. Also model parameters, such as population size and a maximum number of generations are set to be 2000 and 300, respectively. By running the model, a Pareto front that consists 82 solution points obtained. Then for each of the mentioned points, the optimal values of the decision variables are determined. After that, the parameters such as the agricultural production, the related water allocation and agricultural benefit as functions of cultivation area (the optimal values of decision variables) are calculated. In the next step, maximum benefits of all possible coalitions are determined and the benefit of the grand coalition is reallocated to the different regions (for all of the 82 solution points) by applying different cooperative game theory methods. For each of 4 cooperative game theory methods (i.e. Nucleolus, Proportional Nucleolus, Normal Nucleolus and Shapley methods), by applying "Unanimity" and "q-Approval" Fallback Bargaining Methods, the most preferable alternatives among the existing 82 solutions are determined. Then 8 alternatives are chosen, 4 based on UFB and the other 4 based on q-Approval FB (Table 1). Thereafter, among the 4 selected alternatives by each FB methods, the most beneficial alternatives (alternatives with the highest benefit) are chosen as the final solutions which are alternatives 80 and 4 (Table 2). As it can be seen alternative 80 is the outcome of Proportional Nucleolus method while alternative 4 is that of Nucleolus and Shapley methods (Table 1).

Table 1. The most preferable alternatives of the trade-off curve for different cooperative game model

Fallback bargaining methods	Cooperative methods			
	Nucleolus	**Proportional nucleolus**	**Normal nucleolus**	**Shapley**
Unanimity	26	80	13	30
q-Approval	4	81	78	4

Table 2 shows the net agricultural benefit obtained from the results of the grand coalition model. As it can be seen in this table, Gonbad-Kavoos, Minoo-Dasht and Azad-Shahr got rank 1 to 3, respectively. The obtained values in Table 2 depend on both the initial benefit calculated from the M. O. model and the amount of additional benefit due to the participation of the regions in the grand coalition model. The mentioned additional benefit is calculated by different cooperative game methods. The rates of benefit for alternative 80 are 0.6, 0.29 and 0.116 for Gonbad-Kavoos, Minoo-Dasht and Azad-Shahr, respectively, which change to 0.52, 0.3 and 0.173 for alternative 4. Also comparing the total benefit values for the two alternatives depicts that the cultivation area of the valuable crops is more for alternative 4 than that of the alternative 80.

Table 2. Obtained benefit from the most preferable alternatives over 3-year modeling period based on the Cooperative Game Model's result

Selected alternatives	Agricultural benefit (106 $)			
	Minoo-Dasht	Azad-Shahr	Gonbad-Kavoos	Total
26	32.2	22.1	58.1	112.4
80	32.5	13.2	67.6	113.3
13	50.1	20.1	41	111.2
30	35.2	19.1	60.2	112.5
4	34.9	19.85	59.9	114.65
78	40.1	21.1	50	110.3
81	34.3	13.3	63.2	110.8

3.1. Cultivation Area

Cultivation area is an important decision variable which is optimized during the multi-objective optimization process. Table 3 compares the total cultivation area in the three regions based on the results of the M. O. model and obtained results from the cooperative game methods (grand coalition model) by applying UFB (alternative 80) and q-Approval FB (alternative 4) methods for the two most preferable alternatives. As illustrated in Table 3, for the M. O.model, the total cultivation area increases in the second year, while it decreases for the grand coalition model in the same year for both alternatives. The main reason is that Rice cultivation area intensively increases in the grand coalition model in the second year (Figure 3). It is completely rational, because the objective function of the grand coalition model is benefit maximization and Rice is a high expensive crop. Also Rice is a high water consumption crop and its excessive cultivation is a limit for other crops planting that led the total cultivation area to be decreased. The changes of the total cultivation area for each model in each year are relatively the same for both alternatives. Also, the average of the total cultivation area which resulted from the grand coalition model is more than that of the M. O.model.

Table 3. Total cultivation area (ha) over 3-year modeling period for multi-objective optimization model in comparison with grand coalition model

Year	(alternative 80)*	(alternative80)**	(alternative 4)*	(alternative 4)***
1	39559	42844	39895	43046
2	40468	38053	39985	37000
3	37327	39314	37550	39620
Average	39118	40070	39143	39890

*The multi-objective optimization model, ** Grand coalition model (UFB), *** Grand coalition model (q-Approval FB)

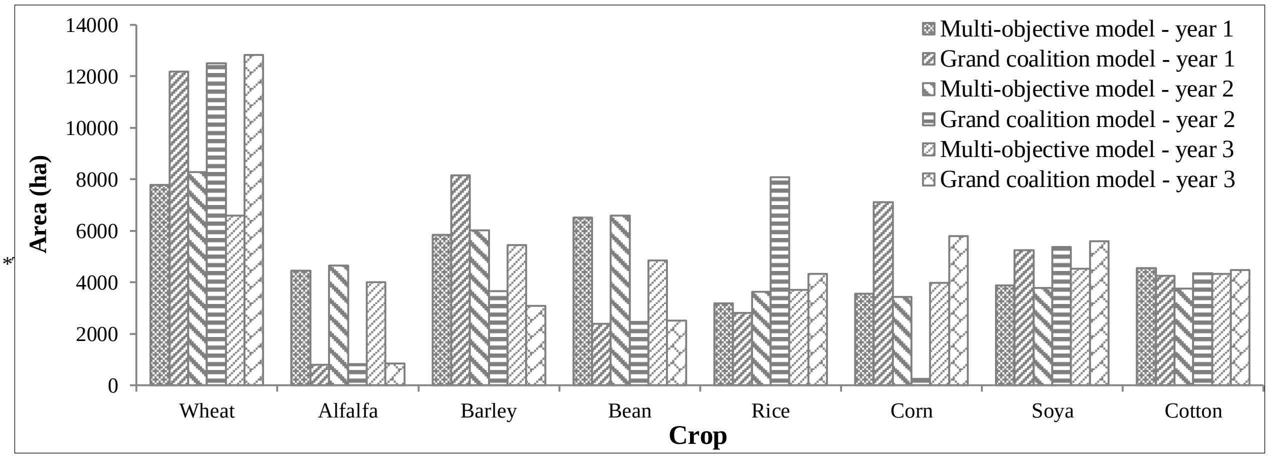

Figure 3. The average of cultivation area for each crop in both models in different years

3.2. Agricultural Benefit

Based on the obtained optimal cultivation areas for each crop and other parameters such as the crops' price and cultivation cost, farmers' benefits are calculated. Though no significant difference in cultivation area between the grand coalition model and the M. O. model results is observed (Table 3), the results show that for the selected alternatives (80, 4) the benefit resulted from the grand coalition model is significantly more than that of the M. O. model in which each region acts separately (Table 4).

Table 4. Total farmers' benefit (106 $) values over 3-year modeling period

Alternative	M.O. model*	Reallocated**	Ratio
80	86.47	113.3	1.310
4	86.3	114.65	1.328

* The multi-objective optimization model, ** Reallocated benefit of grand coalition model

As it can be seen in Table 4, the benefits obtained from selected alternatives by UFB (alternative 80) and q-Approval FB (alternative 4) are 31 and 33 percent greater than the same alternatives of the M. O. model, respectively. From this point of view, there is no significant difference between alternatives 80 and 4 [((114.65-113.3)/114.65)*100 =1.17%), although alternative 4 get 1.35 million dollar benefit more than alternative 80 based on the result of the grand coalition model. Table 5 also shows the benefits of the selected alternatives as the most preferable alternatives for each region in the study area. As it can be seen in this table, Gonbad-Kavoos region obtained the maximum increase in average rate of benefit, while no significant change in benefit ratio is observed for Minoo-Dasht. The values of "Ratio" depicts that the area of each crop in Minoo-Dasht is closely the same for the both models. The similar situation also exists in Azad-Shahr for the alternative 80. In the other cases, the greater values of "Ratio" show that the cultivation is focused on planting the valuable crops with less cost. Also the higher values for the total cultivation area for the case of the grand coalition model in comparison with the M. O. model (Table 3) can increase the benefit for the grand coalition model (Reallocated values).

Table 5. The multi-objective optimization model benefit and reallocated benefit for different regions (106 $)

The most preferable alternative	Minoo-Dasht			Azad-Shahr			Gonbad-Kavoos		
	M. O. model *	Reallocated**	Ratio	M. O. model	Reallocated	Ratio	M. O. model	Reallocated	Ratio
80	32.29	32.53	1.01	13.23	13.23	1.00	40.95	67.54	1.65
4	33.81	34.90	1.03	12.42	19.85	1.59	40.07	59.90	1.49

* The multi-objective optimization model, ** Reallocated benefit of grand coalition model

3.3. Water Saving

Although there is an increase in the average cultivation area (Table 3), Table 6 shows a decrease in water allocation for the both alternatives (80 and 4) for the grand coalition model in comparison with the M. O. model. Accordingly the reduction rate of the water allocation for the UFB (alternative 80) and the q-Approval FB (alternative 4) are 10.5 and 10.2 percent, which lead to 48 MCM and 47 MCM saving water, respectively. As a result, it can be inferred that the share of high water consumption crops with more yield and economical values (Table 4) in alternative 4 is more than alternative 80.

Table 6. Water allocation and saving water for the selected alternatives

Best alternative	Fallback bargaining method	Water allocation (MCM)		Water saving (MCM)
		M. O. model*	Grand coalition	
80	Unanimity	456	408	48
4	q-Approval	460	413	47

*The multi-objective optimization model

3.4. The Trade of Crops

As mentioned earlier, one of the objectives in the M. O. model is to maximize the proportion of (virtual) green water to total agricultural water consumption. Since this objective is a function of cultivation area (decision variable), optimal cultivation area obtained from the model ensures the most extent of (virtual) green water usage in the regions. Based on the obtained results, the import and export rate of crops as the optimal results of agricultural trade are determined. Figures 4 and 5, as well as Table 7, illustrate the amount of import/export of crops for both M. O. model and grand coalition model. The negative values demonstrate import to regions when the production doesn't satisfy its demands and the positive values demonstrate export from regions when the production exceeds its demands. Also, when the trade of crops is about zero, the production almost meets the demands. As it can be seen in aforementioned Figures, the trends for both of the alternatives are the same so that Wheat and Corn are the crops with the most import and export, respectively. Moreover, a change of condition from export to import can be seen for Alfalfa.

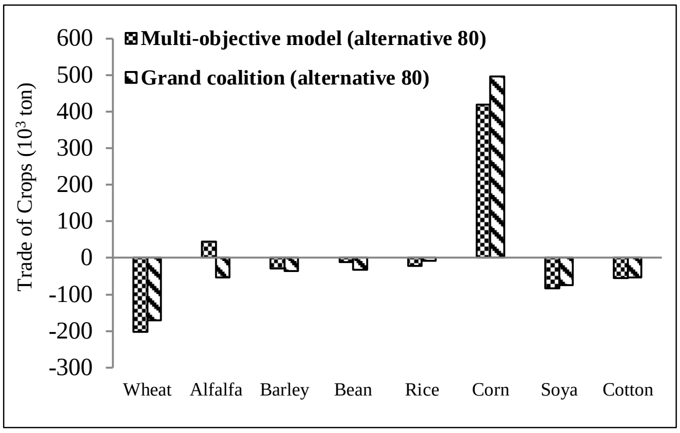

Figure 4. The trade of crops for alternative 80 in the two existing conditions over 3-year modeling period

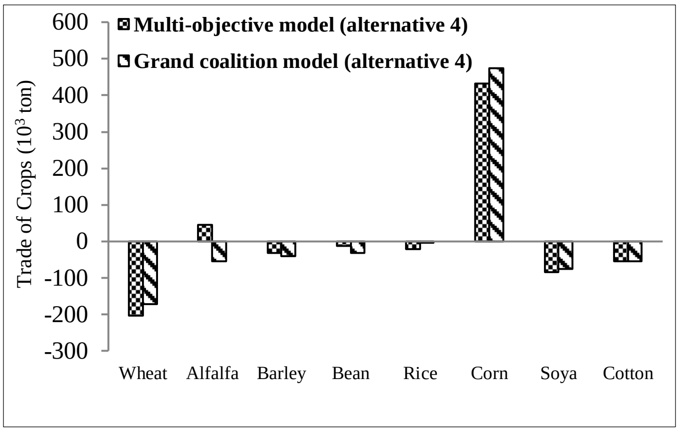

Figure 5. The trade of crops for alternative 4 in the two existing conditions over 3-year modeling period

Table 7. The average of import (-) / export (+) values (ton) for the both model over 3-year modeling period

Alternative	Condition	Crop							
		Wheat	Alfalfa	Barley	Bean	Rice	Corn	Soya	Cotton
80	M. O. model*	-201748	44820	-29596	-11783	-22577	418800	-84133	-54512
	Grand coalition	-171264	-53520	-36823	-32112	-7844	495782	-74928	-53520
	Rate	0.85	-1.19	1.24	2.73	0.35	1.18	0.89	0.98
4	M. O. model*	-202713	45345	-30834	-12385	-21902	431935	-83500	-54152
	Grand coalition	-171264	-53520	-40416	-32112	-3509	474379	-74583	-53520
	Rate	0.84	-1.18	1.31	2.59	0.16	1.10	0.89	0.99

*The multi-objective optimization model

4. Conclusion

In the proposed approach a multi-objective cooperative game model is developed for an important agricultural district located in Golestan province. In our study, eight crops including Wheat, Alfalfa, Barley, Bean, Rice, Corn, Soya and Cotton are selected. The objectives introduced in the methodology are based on equity, economic, soil water utilization, and environmental issues. By solving the multi-objective optimization model for a 3-year period, 82 alternatives obtained as the possible solutions. Then the possible coalitions are formed and for each of them the maximized benefit is obtained. After that, different cooperative games are applied to reallocate the benefit of the grand coalition model for whole 82 solutions. In the next step, the most preferable alternatives are selected by Unanimity and q-Approval Fallback Bargaining methods. The results show that, in the grand coalition model, the cultivation area increases in comparison with the multi-objective optimization model (Table 3) and the agricultural benefit is increased up to 113.98 million dollars on average (Tables 3 and 4). Moreover, 47.5 MCM of water is saved in the grand coalition model (Table 6).

Thus, it is obvious that the grand coalition model's performance is better than that of the multi-objective optimization. It is also noted that Wheat has the most volume of import, although its import is decreased in grand coalition model compared to the multi-objective optimization model (Figures 4 and 5). Furthermore, Corn has the most volume of export (Figures 4 and 5) which in the grand coalition model is more than that of the multi-objective optimization model. For future studies, we propose that a distributed groundwater simulation model to be considered instead of the current lumped model for groundwater allocation. Also, considering the uncertain nature of some data, it is recommended to apply stochastic methods.

5. References

[1] de Fraiture, Charlotte, Ximing Cai, Mark Rosegrant, David Molden, and Upali Amarasinghe. "Addressing the unanswered questions in global water policy: a methodology framework." *Irrigation and drainage* 52, no. 1 (2003): 21-30.

[2] Rijsberman, Frank R. "Water scarcity: fact or fiction?." Agricultural water management 80, no. 1 (2006): 5-22.

[3] Vaghefi, S. Ashraf, S. J. Mousavi, K. C. Abbaspour, R. Srinivasan, and J. R. Arnold. "Integration of hydrologic and water allocation models in basin-scale water resources management considering crop pattern and climate change: Karkheh River Basin in Iran." Regional environmental change15, no. 3 (2015): 475-484.

[4] Faramarzi, M., H. Yang, J. Mousavi, R. Schulin, C. R. Binder, and Karim C. Abbaspour. "Analysis of intra-country virtual water trade strategy to alleviate water scarcity in Iran." Hydrology and Earth System Sciences 14, no. 8 (2010): 1417.

[5] Su, Xiaoling, Jianfang Li, and Vijay P. Singh. "Optimal Allocation of Agricultural Water Resources Based on Virtual Water Subdivision in Shiyang River Basin." Water Resources Management 28, no. 8 (April 12, 2014): 2243–2257. doi:10.1007/s11269-014-0611-5.

[6] Faramarzi, M., H. Yang, J. Mousavi, R. Schulin, C. R. Binder, and K. C. Abbaspour. "Analysis of Intra-Country Virtual Water Trade Strategy to Alleviate Water Scarcity in Iran." Hydrology and Earth System Sciences Discussions 7, no. 2 (April 28, 2010): 2609–2649. doi:10.5194/hessd-7-2609-2010.

[7] Allan, J.A. "Virtual Water: A Strategic Resource Global Solutions to Regional Deficits." Ground Water 36, no. 4 (July 1998): 545–546. doi:10.1111/j.1745-6584.1998.tb02825.x.

[8] Aldaya, M.M., J.A. Allan, and A.Y. Hoekstra. "Strategic Importance of Green Water in International Crop Trade." Ecological Economics 69, no. 4 (February 2010): 887–894. doi:10.1016/j.ecolecon.2009.11.001.

[9] Aldaya, M. M., Chapagain, A. K., Hoekstra, A. Y. and Mekonnen, M. M. The water footprint assessment manual: Setting the global standard, Routledge. (2012).

[10] Chapagain, A.K., and A.Y. Hoekstra. "The Water Footprint of Coffee and Tea Consumption in the Netherlands." Ecological Economics 64, no. 1 (October 2007): 109–118. doi:10.1016/j.ecolecon.2007.02.022.

[11] Li, Y.P., J. Liu, and G.H. Huang. "A Hybrid Fuzzy-Stochastic Programming Method for Water Trading Within an Agricultural System." Agricultural Systems 123 (January 2014): 71–83. doi:10.1016/j.agsy.2013.10.001.

[12] Fracasso, Andrea, Martina Sartori, and Stefano Schiavo. "Determinants of Virtual Water Flows in the Mediterranean." Science of The Total Environment 543 (February 2016): 1054–1062. doi:10.1016/j.scitotenv.2015.02.059.

[13] Liu, Xia, Jiří Jaromír Klemeš, Petar Sabev Varbanov, Lidija Čuček, and Yu Qian. "Virtual Carbon and Water Flows Embodied in International Trade: a Review on Consumption-Based Analysis." Journal of Cleaner Production 146 (March 2017): 20–28. doi:10.1016/j.jclepro.2016.03.129.

[14] Das, Biswadip, Ajay Singh, Sudhindra N. Panda, and Hiroshi Yasuda. "Optimal Land and Water Resources Allocation Policies for Sustainable Irrigated Agriculture." Land Use Policy 42 (January 2015): 527–537. doi:10.1016/j.landusepol.2014.09.012.

[15] Barlow, Paul M., David P. Ahlfeld, and David C. Dickerman. "Conjunctive-Management Models for Sustained Yield of Stream-Aquifer Systems." Journal of Water Resources Planning and Management 129, no. 1 (January 2003): 35–48. doi:10.1061/(asce)0733-9496(2003)129:1(35).

[16] Pulido-Velázquez, Manuel, Joaquín Andreu, and Andrés Sahuquillo. "Economic Optimization of Conjunctive Use of Surface Water and Groundwater at the Basin Scale." Journal of Water Resources Planning and Management 132, no. 6 (November 2006): 454–467. doi:10.1061/(asce)0733-9496(2006)132:6(454).

[17] Karamouz, M., A. Ahmadi, and S. Nazif. "Development of management schemes in irrigation planning: economic and crop pattern consideration." Trans. Civ. Eng 16, no. 6 (2009): 457-466.

[18] Singh, Ajay, and Sudhindra Nath Panda. "Development and Application of an Optimization Model for the Maximization of Net Agricultural Return." Agricultural Water Management 115 (December 2012): 267–275. doi:10.1016/j.agwat.2012.09.014.

[19] Nikoo, Mohammad Reza, Akbar Karimi, Reza Kerachian, Hamed Poorsepahy-Samian, and Farhang Daneshmand. "Rules for Optimal Operation of Reservoir-River-Groundwater Systems Considering Water Quality Targets: Application of M5P Model." Water Resources Management 27, no. 8 (March 2, 2013): 2771–2784. doi:10.1007/s11269-013-0314-3.

[20] Wu, Xin, Yi Zheng, Bin Wu, Yong Tian, Feng Han, and Chunmiao Zheng. "Optimizing Conjunctive Use of Surface Water and Groundwater for Irrigation to Address Human-Nature Water Conflicts: A Surrogate Modeling Approach." Agricultural Water Management 163 (January 2016): 380–392. doi:10.1016/j.agwat.2015.08.022.

[21] Madani, Kaveh. "Game Theory and Water Resources." Journal of Hydrology 381, no. 3–4 (February 2010): 225–238. doi:10.1016/j.jhydrol.2009.11.045.

[22] Abed-Elmdoust, Armaghan, and Reza Kerachian. "Water Resources Allocation Using a Cooperative Game with Fuzzy Payoffs and Fuzzy Coalitions." Water Resources Management 26, no. 13 (August 1, 2012): 3961–3976. doi:10.1007/s11269-012-0115-0.

[23] Nikoo, Mohammad Reza, Reza Kerachian, and Mohammad Hossein Niksokhan. "Equitable Waste Load Allocation in Rivers Using Fuzzy Bi-Matrix Games." Water Resources Management 26, no. 15 (October 9, 2012): 4539–4552. doi:10.1007/s11269-012-0165-3.

[24] Liu, Yaolin, Wei Tang, Jianhua He, Yanfang Liu, Tinghua Ai, and Dianfeng Liu. "A Land-Use Spatial Optimization Model Based on Genetic Optimization and Game Theory." Computers, Environment and Urban Systems 49 (January 2015): 1–14. doi:10.1016/j.compenvurbsys.2014.09.002.

[25] Mehrparvar, Milad, Azadeh Ahmadi, and Hamid Reza Safavi. "Social Resolution of Conflicts over Water Resources Allocation in a River Basin Using Cooperative Game Theory Approaches: a Case Study." International Journal of River Basin Management 14, no. 1 (December 8, 2015): 33–45. doi:10.1080/15715124.2015.1081209.

[26] Wang, L.Z. "Water Resources Allocation: A Cooperative Game Theoretic Approach." Journal of Environmental Informatics 2, no. 2 (December 2003): 11–22. doi:10.3808/jei.200300019.

[27] Mahjouri, Najmeh, and Mojtaba Ardestani. "A Game Theoretic Approach for Interbasin Water Resources Allocation Considering the Water Quality Issues." Environmental Monitoring and Assessment 167, no. 1–4 (July 22, 2009): 527–544. doi:10.1007/s10661-009-1070-y.

[28] Madani, Kaveh, and Ariel Dinar. "Cooperative Institutions for Sustainable Common Pool Resource Management: Application to Groundwater." Water Resources Research 48, no. 9 (September 2012). doi:10.1029/2011wr010849.

[29] Sechi, Giovanni M., Riccardo Zucca, and Paola Zuddas. "Water Costs Allocation in Complex Systems Using a Cooperative Game Theory Approach." Water Resources Management 27, no. 6 (November 6, 2012): 1781–1796. doi:10.1007/s11269-012-0171-5.

[30] Yang, Chao-Chung, Liang-Cheng Chang, Chang-Shian Chen, and Ming-Sheng Yeh. "Multi-Objective Planning for Conjunctive Use of Surface and Subsurface Water Using Genetic Algorithm and Dynamics Programming." Water Resources Management 23, no. 3 (August 8, 2008): 417–437. doi:10.1007/s11269-008-9281-5.

[31] Peralta, Richard C., Ali Forghani, and Hala Fayad. "Multiobjective Genetic Algorithm Conjunctive Use Optimization for Production, Cost, and Energy with Dynamic Return Flow." Journal of Hydrology 511 (April 2014): 776–785. doi:10.1016/j.jhydrol.2014.01.044.

[32] Nikoo, Mohammad Reza, Iman Varjavand, Reza Kerachian, Moharram D. Pirooz, and Akbar Karimi. "Multi-Objective optimumA Design of Double-Layer Perforated-Wall Breakwaters: Application of NSGA-II and Bargaining Models." Applied Ocean Research 47 (August 2014): 47–52. doi:10.1016/j.apor.2013.12.001.

[33] Deb, K., A. Pratap, S. Agarwal, and T. Meyarivan. "A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II." IEEE Transactions on Evolutionary Computation 6, no. 2 (April 2002): 182–197. doi:10.1109/4235.996017.

[34] Nikoo, Mohammad Reza, Reza Kerachian, Mohammad Hossein Niksokhan, and Pouyan Hatami Bahman Beiglou. "A game theoretic model for trading pollution discharge permits in river systems." International Journal of Environmental Science and Development 2, no. 2 (2011): 162.

[35] Alizadeh, Mohammad Reza, Mohammad Reza Nikoo, and Gholam Reza Rakhshandehroo. "Developing a Multi-Objective Conflict-Resolution Model for Optimal Groundwater Management Based on Fallback Bargaining Models and Social Choice Rules: a Case Study." Water Resources Management 31, no. 5 (February 23, 2017): 1457–1472. doi:10.1007/s11269-017-1588-7.

[36] Eschenauer, Hans A. "Multicriteria Optimization Techniques for Highly Accurate Focusing Systems." Multicriteria Optimization in Engineering and in the Sciences (1988): 309–354. doi:10.1007/978-1-4899-3734-6_10.

[37] Ranjbar, Ali, and Najmeh Mahjouri. "Development of an Efficient Surrogate Model Based on Aquifer Dimensions to Prevent Seawater Intrusion in Anisotropic Coastal Aquifers, Case Study: The Qom Aquifer in Iran." Environmental Earth Sciences 77, no. 11 (June 2018). doi:10.1007/s12665-018-7592-2.

[38] Shapley, L. S. "17. A Value for n-Person Games." Contributions to the Theory of Games (AM-28), Volume II (n.d.) (1953): 307-317. doi:10.1515/9781400881970-018.

[39] Shapley, Lloyd S., and Martin Shubik. Game Theory in Economics: Characteristic function, core, and stable set. Vol. 6. Rand, 1973.

[40] Young, H. P., N. Okada, and T. Hashimoto. "Cost Allocation in Water Resources Development." Water Resources Research 18, no. 3 (June 1982): 463–475. doi:10.1029/wr018i003p00463.

[41] Lejano, Raul P., and Climis A. Davos. "Cooperative solutions for sustainable resource management." Environmental Management 24, no. 2 (1999): 167-175.

[42] Shoubi, Mojtaba Valinejad, Azin Shakiba Barough, and Omidreza Amirsoleimani. "Application of Cost Allocation Concepts of Game Theory Approach for Cost Sharing Process." Research Journal of Applied Sciences, Engineering and Technology 5, no. 12 (April 10, 2013): 3457–3464. doi:10.19026/rjaset.5.4593.

[43] Sheikhmohammady, Majid, and Kaveh Madani. "Bargaining over the Caspian Sea — The Largest Lake on the Earth." World Environmental and Water Resources Congress 2008 (May 2008). doi:10.1061/40976(316)262.

[44] Brams, Steven J., and D. Marc Kilgour. Group Decision and Negotiation 10, no. 4 (2001): 287–316. doi:10.1023/a:1011252808608.

[45] Iran, Golestan regional water company. 2010. The final report of updating the Golestan basin and water resource balance study.