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A Multi-Objective Bargaining and Fuzzy Programming Approaches for Optimal Water Allocation with Emphasis on Deficit Irrigation

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Introduction: Due to the rapid rate of population growth, water resource topics wasmainly affected by the economic and social components, however, the importance of environmental issues in such projects has gained more attention. As pollution loads are increasing, it has become more essential to incorporate water quality in water resource management issues. Under this condition, optimal water allocation by considering multiple objectives of water quality and quantity issues can lead to sustainable and optimal benefit of stakeholders. This study was done in order to balance environmental and economic concerns in water resource allocation.

Materials and Methods: Based on game theory concepts and fuzzy programming procedure, two new methodologies were developed for sustainable water resource allocation in river systems. The proposed methods which include a multi-objective bargaining and fuzzy programming approaches were utilized to analysis strategies of interaction between environmental protection and economical income. Two groups of players, consists of player 1 for environmental and player 2 for economic issues were considered in order to apply the developed models. As players will not be satisfied with the outcome of each other, they will begin the bargaining process. Throughout the bargaining rounds, players will reduce their expectations. After several negotiations, the interval between the reset goal values and outcomes will be decreased. The bargaining process will be finished if final solutions reach to the determined goals. In the study, the Total Dissolved Solids (TDS) were considered as water quality indicators of environmental objective function, since salinity is the important problem of the study area. Using crop production function in economic income objective function makes it possible to incorporate deficit irrigation in different crop growth stages. Since allocation problems include many decision variables, conventional (non-linear) crop production function will have high computational costs and linear form of it can reduce the complexity of the optimization model. Therefore,additive (linear) form of crop production function was taken into consideration instead of multiplicative form. Total pollution load discharged into the river (ton per year) and economical income of the system (thousand dollars per year) wasconsidered as environmental and economic values, respectively. During the fuzzy programming procedure, the purpose is to achieve a compromise solution. In this approach, the individual maximum and minimum values of objectives is used to define the membership function. This procedure will maximize the satisfaction degree of the constructed membership functions of the objectives. The presented methodology was illustrated in a part of Karoon-Dez river system between Gotvand dam, Dez dam and Ahvaz city, as a case study. The area of Karoon-Dez river basin is about 67000 square kilometers and it is located in the southwestern part of Iran. The selected area includes 8 agro-industrial and 3 traditional agricultural sub-sectors.

Results and Discussion: Using a linear form of crop production function for calculating the total benefit of the system leads to significant reduction in run-time of the optimization model and make irrigation programming possible by regarding crop growth stages and the available water amount. The results of this study showed that Nash equilibrium, which provides a base for decision makers to choose a strategy, was reached at the fourth round of bargaining process. Moreover, balance between economic and environmental objectives is available by reducing economical expectation and environmental concerns from 553636 to 496216 thousand dollars per year and from 68264 to 87251 tons per year, respectively. In these cases, the annual allocated water to environmental and economical player will be 6123 MCM (5318 to agro-industrial sub-sectors and 805 to agricultural sub-sectors) and 6453 MCM (5730 to agro-industrial sub-sectors and 723 to agricultural sub-sectors) respectively. The results of the fuzzy programming approach demonstrated that at optimal condition, environmental and economic objective function was 85999 tons per year 500422 thousand dollars per year, respectively and allocated water to water users are 6354 MCM per year (agricultural and agro-industrial sub-sectors of the system will be (763 and 5591 MCM per year). Agro-Industrial sub-sector 3 will take the maximum allocated annual water (1789 MCM per year) and Agro-Industrial sub-sector 5 will receive the minimum annual allocated water (151 MCM per year). Comparison of two investigated approaches showed that their results are in agreement with

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each other.

Conclusions: Results of applying the developed methodology to the Karoon-Dez river system demonstrated that it is effective and applicable to determine sustainable water allocation policies. Finding of this study reveals that the proposed framework can facilitate decision-making process and optimize allocated water to different water users under conflicting objectives. Therefore, the developed procedure can be used as a managerial tool for optimal water allocation strategies, which is in accordance with sustainable development approach. It is easy to apply the presented methodology to other river systems with high pollution loads of agricultural return flows.

Keywords: Crop response function, Multi-objective optimization, Nash equilibrium, Water allocation, Water quality