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

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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.

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