Optimization of Water Allocation Using Cooperative Game Theory (Case Study: Zayandehrud Basin)

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Expanded Abstract

Introduction
There is no determined value for water (as a public asset) by its trustees and beneficiaries and its allocation method is more dependent on the requirements of water consumers than comparison of benefits of water affairs with its real value. This is a game to decide which interested group, when and to what extent can use the water. This study is aimed to determine sustainable policies for allocation of water to the interested groups such that high quality and sufficient water is available to survive water bodies and economic purposes of interested groups are also satisfied by sustainability agreement with the environment. For this, the environment is recognized as an independent water user in optimization model and as an independent player in the game theory. Thereby, Zayandehrud Basin has been studied as a case study.

Materials and Methods
The study hasfirst dealt with optimization of the water allocation from the reservoir to consumptions including drinking, agriculture, industry and environment by means of genetic algorithm. To get the most desirable possible state of water supply for consumptions, 4 approaches have been considered, as described briefly below.

The first is supply of biological flows for the rivers which are in an equilibrium using Tenant (Montana) method and available data (providing 2.06 mcm for each month in the cold season and 6.18 mcm for each month in the warm season). The second is supply of the minimum water requirement for lagoon survival and protection of the minimum requirements for the valuable water ecosystem in the area. Continuity of natural life in the swamp depends completely on water depth. The lowest possible depth for vital activities is the depth of about 15 cm. This depth can be achieved by importing 75 mcm of water per year into the swamp. Benthos is hardly survived in this depth. The third includes supply of water with desirable quality for the lagoon based on TDS such that the water requirements for TDS dilution have been assumed as biological requirement. In the fourth, supply of the minimum water requirement for the lagoon is considered with regard to the studies on Gavkhoony swamp, desirable performance occurs with supply of 140 mcm of water per year. This amount provides depth of 30cm for the swamp. Then, having estimated the benefits of each beneficiary, the interactions among the beneficieries in the basin have economically been investigated by cooperative games.

Results and Discussion
With regard to the data of the study area, in spite of various managerial plans to increase water supply for the basin, it no longer satisfies the requirements of water consumers. Specially, it is the case in the environmental sector. Because of ignorance and devoting water allocation priorities in the recent years, the environmental sector has experienced deficient and is completely dependent on seasonal flows and rainfalls. According to the designed approaches in the environmental sector of this study area, more than 85% of its requirements can be eliminated in allocations. With water supply approach for environment sector, 3-8% of agricultural and 8% of industrial requirements are faced with deficient. From environmental requirement point of view which has been distinctively defined in every approach, the model has shown the best performance in the first approach such that 100% of environmental requirements are satisfied. Given that this approach has accounted for the minimum requirements for the environment, minimum deficiencies have been observed in agricultural and industrial

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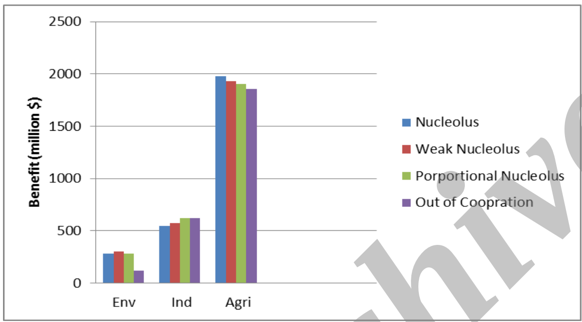
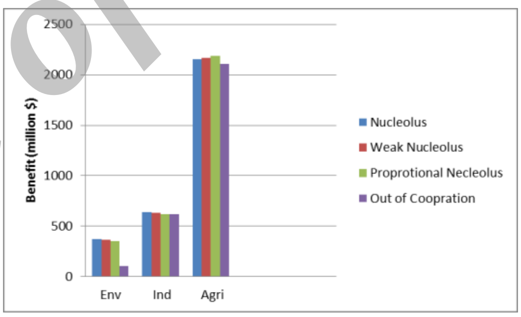
allocations. Maximum water requirement has been considered in the fourth approach in which the optimization model has allocated 87% of the supply to the environmental requirements. From view point of water allocation to the environment, the fourth approach is the best in that the supply with regard to water content as well as positioning of the lagoon is in a desirable state for survival.
The percentages of requirement for beneficiaries and annual water allocations have presented in Table 1 for different approaches. The benefits of each beneficiary and the results of cooperative game have been illustrated in Figure 1.

Table 1. Gross profit of water users in each approach

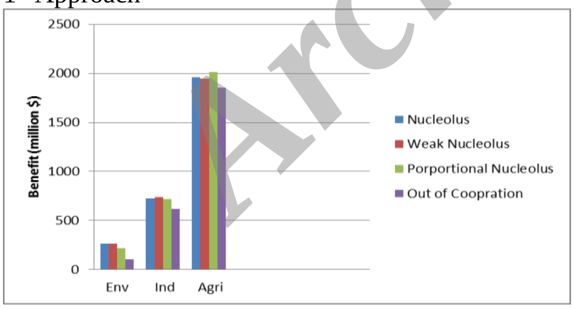
User	1st approach		2nd approach		3rd approach		4th approach	
	Water use (MCM)	Benefit ($)	Water use (MCM)	Benefit ($)	Water use (MCM)	Benefit ($)	Water use (MCM)	Benefit ($)
Agriculture	8759	2057.89	9182.32	2157.34	8652.6	2032.89	8756.8	2057.38
Industry	924.17	622.47	924.21	622.49	923.61	622.09	924.3	622.55
Environment	985.05	117.16	890.71	106.03	1044.98	124.4	1747.2	208



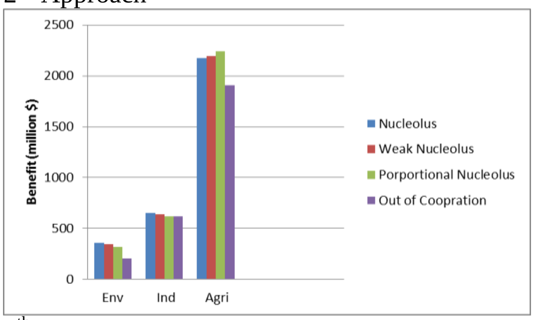
1^{st} Approach



2^{nd} Approach



3^{rd} Approach



4^{th} Approach

Fig.1. Results of cooperative games in different approaches

Conclusion

It can be concluded from the economic analyses of the model approaches that the industry has the same benefit in all approaches despite 8% of change in water allocation. With unfair allocation and low or high environmental utility in different approaches it has no influence on economic performance of the industry. The second approach has the most benefit in agricultural sector and the best performance in environmental sector because of the most desirable state for the river and lagoon survival. Economic analysis shows that agricultural sector has more benefit in second approach than other states. From model allocations, it can be said that monthly allocation and distribution model has impressive effects on the agricultural sector. With constant optimization procedure in the allocations, agricultural sector incurs severe pressures. In the allocated water and benefits in the agricultural sector, the second and fourth approaches have little differences because of monthly water distribution procedure in the first and third approaches.

According to game theory, the benefits from player cooperation in agricultural and environmental sector have been more than no cooperation. The industry earns the same benefit from both states, except for the third approach. Proportional Nucleolus game has the maximum benefit in agricultural sector, except in the first approach. Weak Nucleolus has shown better performance in benefit calculation in the environmental sector, except for fourth approach. Therefore, there is no specified procedure for games but because of more benefit from cooperation in agricultural and environmental sectors the two sectors will get more benefits from cooperation beside water supply requirement. The best benefit allocation has respectively occurred in fourth, second, third and first approaches.

Finally, it is clear that considering the environment as a beneficiary of the basins and planning for water resource management makes always more benefit in the system, although less water allocation to consumers makes less benefit. Because of no profit in the environment sector and no protest against deficiency in the sector, except in critical conditions, this is ignored while water ecosystems are the most valuable resources that their economic value estimation is complicated.With these economic methods it is seen that there are aggregate benefit and profit in the environment protection and survival.

Keywords: allocation, environmental flow, game theory, optimization, Zayandehrud River.