SIMULATION AND OPTIMIZATION OF INTER BASIN VIRTUAL WATER TRANSFER MANAGEMENT BY GAME THEORY APPROACH

DEHGHAN MANSHADI H.R.[1], **BASHIRI A.**[2] **and ASADI M.**[2]

[1]Student of Engineering Program, Humber College, Toronto, Canada,[2] M.Sc. Student, Faculty of Environment, University of Tehran, Tehran, Iran. [3] B. Sc. of civil engineering, Azad University, Tehran, Iran
E-mail: Hr.dehghan@ut.ac.ir

ABSTRACT

Temporal and spatial water distribution in basins and watersheds, water quality and quantity, uncertainty about the obtained estimations are important issues to consider in order to achieve an efficient basin management. In addition, Simulation of hydrological phenomena is very important when a basin lacks sufficient hydrological stations. In this study, the distribution model of SWAT (soil and assessment tools) is used in Rafsanjan basin in Iran in order to simulate and estimate the virtual water parameters such as Blue Water (sum of surface runoff and deep underground water supply), Green Water (actual evapotranspiration) and Green Water Storage (soil water). Different scenarios with the aim of optimizing water productivity have been proposed in order to decrease the economic and environmental impact of water transfer project. Furthermore, the best management scenario among them is determined based on its weighting function and game theory. Furthermore, the automated calibration software, which is linked to SWAT, is used to calibrate and validate monthly flow of river.

Keywords: Basin, management, Blue Water, Green Water, SWAT model

1. Introduction

Iran is located in an arid and semiarid region of the world. It has non-uniform temporal and spatial distribution of water resources and water demands. The periodic droughts and water deficits lead to the migration of inhabitants in certain regions. In addition, considering the rate of population growth and the improving economy, it is necessary to have long term planning to balance the supply and the demands distribution. Besides, The inter-basin water transfer project is an alternative to balance the non-uniform temporal and spatial distribution of water resources and water demands. Transferring water from an area may cause a variety of negative impacts, social and environmental impacts. Principally population growth is the main cause of global water crisis and it can be called as “The Mother of Water Crisis”(Dehghan Manshadi,2012)

The world’s average per capita available water consumption is currently 6660 cubic meters. Each Iranian uses less than 1750 cubic meters per annum and the average total volume of water of the country that can be harvested is about 130 billion cubic meters. The average per capita water of Iranians in the past three decades has decreased about 50% falling from 3500 to 1750 cubic meters for each person per annum. If in the year 1400 the population increases to 100 million, water usage per capita of each person will be 1300 cubic meters per annum. When the per capita water usage of each person reaches 2000 cubic meter per annum, it will enter the stage of water stress and 1500 cubic meters is determined as a water scarcity line.Young *et al*. (1982) listed Iran as one of the countries affected by water scarcity after 2000 and concluded that it will have less than 1500m3 renewable water resources for each person per annum by 2030. Oki and Kanae (2004) presented descriptive statistics about virtual water exchange and indicated that countries experiencing Water Crisis can overcome this critical situation by taking the virtual water exchange into account. They concluded that by considering virtual water exchange, they are able to introduce a better index representing water shortage. Furthermore, they expressed that by adding virtual water to water resources of a country, the country may be able to reduce its water resources scarcity or even eliminate it.

The term "Virtual Water" was first used by Tony Allen to refer to the amount of water available and accessible in the global system through the exchange of agricultural goods. (Allan,1997).Before 1993, the term “Embedded Water” was used to refer to the same concept, but it was unable to attract water resources managers’ attention. The word ‘virtual’ refers to the fact that the amount of water used to produce a product is a lot more than the amount of water inside it. In another words, water inside a product if it exists, compared to its virtual water is negligible.

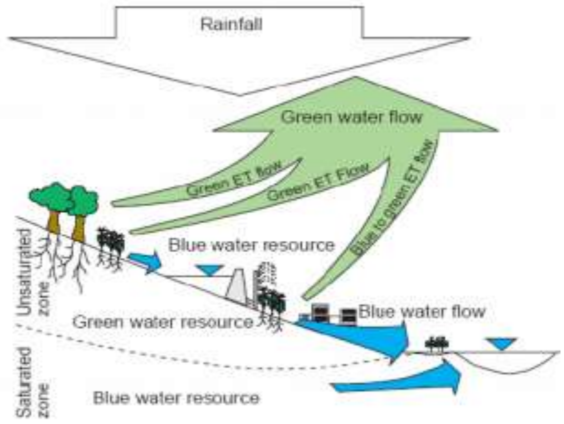

Figure 1: Green and Blue water

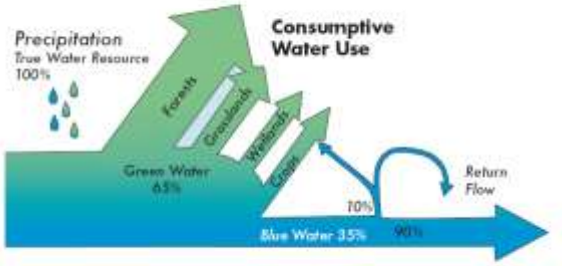

Figure 2: Balance of freshwater

As figure 1 indicates water from runoff, lakes, dams, rivers, wetland, groundwater in saturated area forms blue water and soil moisture in unsaturated area forms green water. Figure 2 presents balance of freshwater reservoirs and compares the amount of blue and green water. Rainfed agriculture is mainly fed by green water produced by rainfall. According to the role of these two in food production it can be said that blue water and green water are the source of blue water the importance of which represents itself in agriculture section. Minimum and maximum of green water (Evapotranspiration) of agricultural lands all around the world are estimated 4900and 9800Gm3.y-1 respectively. (Rockstra and Gordon 2001) which is Notable.
Several investigators have emphasized the need for economic and environmental assessment of inter-basin water transfer plans. Lund and Israel (1995) presented the application of multi stage linear programming for estimation of the least-cost integration of several water marketing opportunities with water conservation and traditional water supplies. Karamouz *et al*. (2004) reviewed water transfer project in the form of a national necessity, economic, and environmental awareness of the effects of this project. Jing *et al*. (2006) compared the amount of blue water transferred from south to north by inter-basin south to north water transfer project to green water transferred in virtual water trade form in china and found out that 52 billion m^3 of water in virtual form is transferred to south China, which was more than the maximum proposed water transfer volume along the three routes of the Water Transfer Project from south to north.

2. Methodology

In this article, a single-object optimization model with an economic objective function in water resources allocation of interbasin water transfer project is developed. For discovering environmental impacts, minimum of environmental inflow and quality of downstream are applied. An interbasin water transfer plan is studied and analyzed in this paper as an example of water resources development plan by virtual water approach to evaluate the importance of virtual water in water resources management. The proposed model is based on attaining the maximum benefits with the minimum costs among three parts in Iran. First one is Rafsanjan’s agriculture which has pistachio as its main crop cultivated. The main purpose of interbasin water transfer is due to the required water for this part. The second one is Khoozestan's agro-industrial part, which has sugar beets as its main crop cultivated. Khoozestan's agriculture is the third receiver and its main crop cultivated is wheat, barely, corn, potato, tomato. To evaluate the economic impacts of virtual water model and water resources allocation systems, two different scenarios are used. In the first scenario the data of inter-basin water transfer project from Solegan to Rafsanjan is used on a monthly scale for a year. In this scenario the maximum net benefit and the monthly quantitive allocated water between parts are calculated. In the second scenario water allocation in the form of virtual water with qualitative and quantitative objective function is studied and the final results are compared with the results of Mahjouri *et al*.(2010). For Optimization model, the micro-GA algorithm indicates the monthly water allocation to the sending and receiving basins considering the benefit-cost analysis. Also sensitivity analysis has been done to evaluate the impact of the price of agricultural product on the net benefit. Two terms of calculation of virtual water of agricultural goods and the index of CPD are discussed briefly in order to be able to continue calculation.

3. Structure of optimization model

The main objective of the proposed benefit-cost model is to maximize the difference between the associated benefit and cost:

$$\text{Maximize } Z = \sum_{n=1}^{2} B_n - \sum_{k=1}^{3} C_k \qquad (1)$$

In this equation, k shows index of the cost; n represents index of the benefit; i indicates interest rate; B_n shows the benefit of the water transfer project in month m of year y and C_n indicates the cost of the water transfer project in month m of year y. The objective function includes the total benefits and total costs of the inter-basin water transfer project. B1 shows the total benefit of selling agricultural products of sending and receiving basins. B_2 represents the total groundwater pumping cost in Rafsanjan's basin which will remain after transferring water to this basin. C_1 indicates the increase in dredging cost due to decrease in the discharge of the downstream point of river, in sending basin of the water transfer. C_2 shows the capital and OM costs of the water transfer project. C_3 illustrates the cost of the hydropower generation reduction. For further information about details of the objective function see also Dehghan Manshadi et.al (2013).

4. Case study

Figure 3 illustrates the location of sending and receiving basins. Namely, one sending basin in Khoozestan (in the western part of the country) with a receiving basin including Rafsanjan plain in Kerman (in the central part of the country) are considered as case studies.

Karoon River basin is located in Iran's four provinces of Khoozestan, Lorestan, Chaharmaholo Bakhtiari and Kohkiloye va boyerahmad. Its area to the estuary of the Persian Gulf is about 67000 km^2.

Figure.3: location of sending and receiving basins in Iran

Rafsanjan has hot summers and dry winters. Average annual rainfall is about 90 mm. The major objective of this water transfer project is to supply water demand of Rafsanjan plain agriculture for production of pistachio. The Water Transfer project from Solegan to Rafsanjan is designed for supplying an average of 250 MCM per year.

5. Result and discussion

The proposed model is solved using the Micro-GA algorithm. In the Micro-GA setting of this study, there is one decision variable in each month, which are the transfer flows from Solegan Tunnels to Rafsanjan.

The second scenario uses the quality and quantity of virtual water data to calculate agricultural products of sending and receiving basins. Since virtual water data may be different due to the variety of Iran's climatic conditions, the virtual water data of products of the same basin is applied in this model.

On the whole, the benefit of the project has been risen two times more than the initial benefit. The benefit of agricultural products should be considered, since it has an influential effect on the total net benefit. Although, Rafsanjan agriculture's CPD is lower than the two other players, the final price of its product is far more expensive than the final price of two other players' products. Moreover, it has obtained more benefit by participating in Grand Coalition. In this regard, 4 different methods of cooperative game theory such as Shapley value, proportional nucleolus, weak nucleolus and nucleolus are applied and compared with the initial right of allocation. For more information about this methods refer to Young *et al*. (1982) and Sadegh and Kerachian (2011). Results of reallocation of economic net benefits presented in Fig.6. According to this figure, by individual performance and non-participation in cooperative games, the three main water users, received the economic benefit based on their business model.

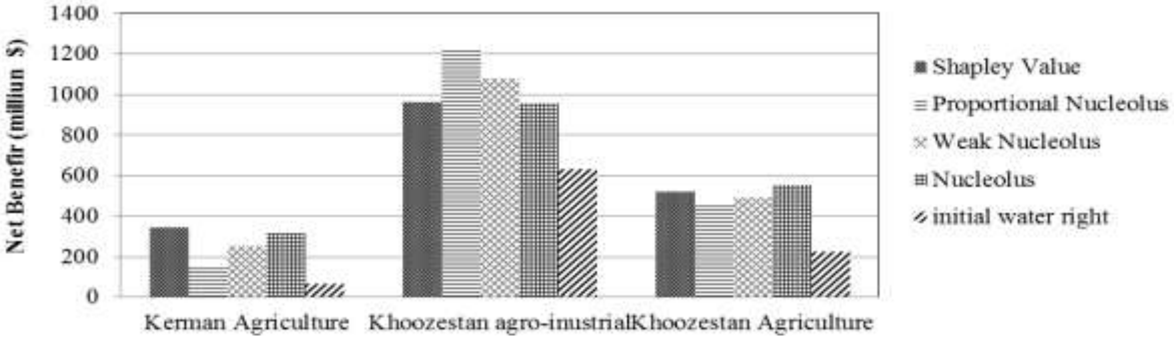

Figure 4: Economic benefits allocated to the various coalitions and methods of reallocation of economic benefits during the 30-year planning

In order to examine the qualitative effects of virtual water in downstream of the transfer reservoir and estuary of rivers that flow to surface water, the information of Dabrowski et. al(2009) is used. In this paper, phosphorus and nitrate exist in phosphate and nitrate fertilizers which were used in Khoozestan agriculture and their effects on discharging to surface water are studied. According to local standards allowable concentrations of NH4 and PO4 are respectively 50ppm and 6ppm. The amount of required fertilizer is obtained from Iran's Agriculture ministry. according to Dabrowski et. al(2009) researches, the required amount of virtual water required for quality assessment evaluated.

The net benefit of the first scenario is estimated to be 2964 million dollar and the characteristics of each plan are presented separately in the table 2. As it is shown the agricultural parts of scenario1 and scenario 2 have the most benefit with the amount of 2996 and 2989 respectively due to the high value of products, specially pistachio. The most important cost value is related to the total annual estimated constructional and operation and the cost of decreasing hydropower dam.

Table 2: Benefit and Cost of various scenarios (million dollar)

	Net Benefit	Benefit of Agricultural Product	Benefit of groundwater pumping	Cost of power	Cost of dredging	Cost of operation and construction
scenario1	2964	2996	0.000142	0.017	1.99	29.9
scenario2	2957	2989	0.000141	0.017	1.99	29.9

The results of this model is compared with the results of Mahjouri *et al*.(2010) model which was concerned with water allocation based on blue water. The table 5 present the comparison of net benefits of two models obtained from water transfer.

6. Summary and conclusion

This paper employed a new approach for applying quality and quantity of virtual water concept in water allocation of inter-basin water transfer in two different scenarios. In the first scenario, the calculations were based on required Virtual Water quantity data of agricultural products and in the second scenario; the calculations were based on Virtual Water Quality and Quantity data of agricultural products in sending and receiving basins. For analyzing the model efficiency, water transfer design from Solegan in western part of Iran to Rafsanjan Plain in central parts of the country was studied.

The results of this model is compared with the results of Mahjouri *et al*.(2010) model which was concerned with water allocation based on blue water.The net economic benefits of the project by considering virtual water in Mahjouri *et al*. (2010) was less than half of the benefits in the absence of virtual water effects in our scenario. In addition, the cases where the amount of water allocations were based on the virtual water, the amount of water allocated to the parts which had less productivity was reduced. Therefore, it can be said that if the calculation of water allocation is not based on virtual water, not only the equity element is not considered in the allocation system, but also the benefits and costs are not calculated accurately. At the end, sensitivity analysis indicated that the net benefit is sensitive to the prices of agricultural products.

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