J. Agr. Sci. Tech. (2011) Vol. 13: 477-490

Economic Optimal Allocation of Agriculture Water: Mathematical Programming Approach

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ABSTRACT

Due to increasing demand for the scarce available water throughout the world it is an extremely important matter, in water management, to make serious attempts in determining its true economic value. This paper discusses the optimal allocation of water to agriculture, the relatively true economic value of water as well as the cropping patterns for the Shirvan Barzo (SB) dam area in North Khorasan Province of Iran. The analysis is based on linear programming (LP) and on multi goal linear programming (MGLP) models for determining solutions that can maximize net return to farmers. In the study, the priority of goals is developmental, social, economical, and environmental respectively. The results indicated that optimizing the cropping patterns along with proper the allocation of irrigation water has yet substantial potential to increase the net return from agriculture. It has already decreased the applied water as much as 19 percent. The results show that the economic value of each unit of agricultural water is estimated to be between 107 to 1296 IRR$\times^{104}$ per cubic meter. This suggests managing the allocation of water based on optimal models and bring water prices close to its true economic value to motivate the farmers to economize in the applied water.

JEL Classification: Q12, Q25

Keywords: Economic value of water, Cropping pattern, Mathematical Programming Optimal Allocation, Sustainable irrigation.

[DOR: 20.1001.1.16807073.2011.13.4.11.0]

INTRODUCTION

Water scarcity has become an increasing social and economic concern for the policy makers and as well for the competitive water users. Particularly, agriculture is becoming the sector to which policy makers are pointing out as the core of the water problem (Koundouri *et al.,* 2006). Water as one of the most valuable natural resources, is demanded by multiple sectors. It is one of the main production inputs in agriculture and has a specific and substantial role in sustainable development of agriculture (Dinar *et al.,* 1997). The nature of problems involving water is typically one of conflicts among alternatives stemming from economic scarcity. The conflicts maybe of various types, examples including competition among kinds of uses, between geographic location of uses, and between current and future uses. Therefore for these reasons, we believe an examination of economic concepts underlying water allocation is needed among areas, based on an economic value of water (Ward *et al.*, 2002).

An adoption of long-run policies and approaches is needed for efficient management of water resources to help with reducing constraints, decreasing social conflicts and increasing the social standing and economic value of water. The protection and optimal allocation of water resources

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needs to be a major priority in both national and regional programs (Keramatzadeh, 2005).

Due to the high cost of capturing and holding water, two approaches are suggested; increasing the amount and extent of available resources in a region (such as building a dam); increasing agricultural water productivity. The first approach is obviously very costly and in some cases impossible. The second approach is rationally acceptable, especially in such dry or semi-dry regions as Iran. An application of different productivity methods is needed to increase or maximize profit in an agricultural sector with the existing resources. Namely, changing water resources management from a supply-based management approach into a demand-based management one has changed the agricultural water pricing system into an economic based value of water. This last approach is one of the most efficient instruments for rational allocation of scarce water across the region (Alizadeh and Keshavarz, 2005).

Water demand management means the establishment of equilibrium between constant supply and economic demand of agricultural water. Water pricing policies play a major role in establishing equilibrium. If the price of water is properly determined, many of the existing problems in water management would be resolved (Gibbons, 1987).

The most important role of economic water pricing as a key instrument in demand management, is its optimal allocation among different regions. Another role of economic water pricing is to encourage thrift in its consumption and prevent water waste. A low price may result in a lowered willingness to both protect it and ensure its most economical use. On the other hand, if water is overpriced to more than its marginal value, farmers will reduce their use of it. Such an agricultural water pricing policy would be in contrast with the purpose of agricultural growth and an increase of income to farmers. Therefore, if the price of water is properly determined, water will not be wasted and incomes will increase (Kumar *et al.,* 1998).

The existing problem in water management in Iran is its optimal allocation among different agricultural activities as well as its other uses that are becoming more acute because of increasing demand for water. Nevertheless, water allocation among users in many regions in Iran is performed under local government management and is often based upon political-social regulations instead of economic criteria. This kind of water resources management has resulted in a non optimal allocation of water in Iran (Ministry of Power, Iran, 2005).

Mainuddin *et al.* (1997) formulated an LP model to obtain an optimal cropping pattern and used LINDO software to solve the problem. Doppler *et al.* (2002) investigated the impact of water price strategies on the allocation of irrigation water by using an LP model to determine solutions to maximize gross margins. The results of the study indicated that optimization of cropping patterns and the allocation of irrigation water has increased the returns from agriculture. Cheng *et al.* (2008) presents an LP model to study the conjunctive use of surface water and groundwater for optimal water allocation. The optimal ratios for allocating water running in three canals are analyzed in this research. They indicated that optimal distribution rate for each canal depends on the season, irrigation methods and crops. Various reports (Yaron and Dinar, 1982; Chavez Morales, 1986; Raju and Kumar, 1999; Amir and Fisher, 1999; Al-Weshah, 2000; Salman *et al.,* 2001; Singh *et al.* 2001; Samei Tabieh, 2007) address optimal cropping pattern and optimal allocation of water by using LP model. They observe considerable improvement in the economic return as well as in the utilization of land and water resources by adopting an optimal cropping pattern. However, the mentioned studies take applied water as a constraint in the LP modeling not considering the transformability of water from one period to another through such reserving tools as reservoir dams that are considered in this study. Reca *et al.* (2001) developed a non-linear objective function to optimize water allocation, but in order to solve the model, they transformed it into a linear problem by approximating the benefit function to a discrete function. Kholghi (2001) presented a methodology for a wastewater planning management system in Iran. This method permits the decision makers to select the best solution according to his viewpoints. This method proceeds in two steps: the assessment of optimal utility using piecewise LP techniques and sensitive analysis using a post optimal procedure. Hung *et al.* (2006) looked at a new water policy, namely increasing water prices in order to provide water users with direct incentives to save water. The estimation results showed that water is severely under priced in their sample areas in China. They stated that water users may probably not respond to increases in water prices. Thus, the first step to establishing an effective water pricing policy is to encourage policy makers to increase the water price to the level of value marginal product so that water price reflects the true value of water. Wang *et al.* (2008) have developed a dynamic model for equitable distribution of water in water-shortage areas and aims to optimally satisfy the requirements of each locality, given limited supplies, and to maximize the total economic benefit of the entire area. In general, all the researches show that optimal allocation of water has considerable impact on farmers' net returns, and saving of water should be done in different arid and semi-arid districts.

Some studies in Iran (Torkamani *et al.,* 1997; Hosseinzad and Salami, 2004) have estimated the economic value of irrigation water through mathematical programming and production functions of crops that are 6 and 390 IRR respectively, but with the optimal allocation of water not having been taken into consideration.

Multiple Goals Linear Programming Model (MGLP) models as one of the prominent tools for multi-objective decision analysis, aim at minimizing the deviation of the objective value from aspiration levels specified by decision makers. There are three major models in MGLP which are most widely used as lexicographic or preemptive MGLP (LMGLP), weighted MGLP (WMGLP) and minmax MGLP (MMGLP) (Yaghoobi and Tamiz, 2007), two models of which (LMGLP and WMGLP) we applied for a determination of economic value and optimal allocation of water and then the obtained results were compared with those obtained through LP model.

Study Area

Iran is located in a semiarid region of the Middle East. The average precipitation is 252 mm per year and annually about 130 BCMs (billion cubic meters) of water (Surface water 105 Groundwater 25) are accessible from which about 88 BCM are currently used up each year. The greatest volume of accessible water in Iran goes to agriculture sector (92.8 percent). The shares dedicated to domestic and industrial purposes are 6 and 1.2, respectively. The overall irrigation efficiency in Iran is reported as 30 to 35 percent and the water productivity as the amount of produce per unit water applied in the field is 0.75 kg per cubic meter (Alizadeh and Keshavarz, 2005).

At present, the main institution for water resources management is based in the Ministry of Energy, with its main components as: Deputy Minister for Water Affairs, regional water companies, Water and Wastewater Engineering Company, provincial water and wastewater companies, and the close cooperation of the Ministry of Agriculture. Furthermore, about 124 consulting firms and 216 construction companies support the above executive organs and institutes (Ardakanian, 2005).

The construction of dams has always played an important role in harnessing Iran's water reserves and the long-term objective of Iran's water resources development plan. It is based on the control and regulation of water resources through building dams. In 2005, 85 storage dams were being exploited with a total regulation capacity of 24.85 BCM. At the same time, 86 storage dams were under construction with a designed capacity of 9.94 BCM (Ministry of Power, Iran, 2005).

The method explained above has been applied to the lower part lands of SB Dam, located in Northern Khorasan Province of Iran (Figure 1). The dam has been built on Gholjogh River with a 44.4 MCMs (Million Cubic Meters) total regulated yearly capacity out of which 16.7 MCMs are dedicated to agricultural water rights, and 13.5 MCMs remaining as surplus water. A volume of 14.7 MCMs goes to Shirvan city as potable water. The water charge paid by farmers is only 35 rials per cubic meter.

The lower part lands of Shirvan Barzo (SB) Dam consist of three regions namely GOL, ZIA and SEY with 1,150, 2,465 and 842 hectares respectively, form which the

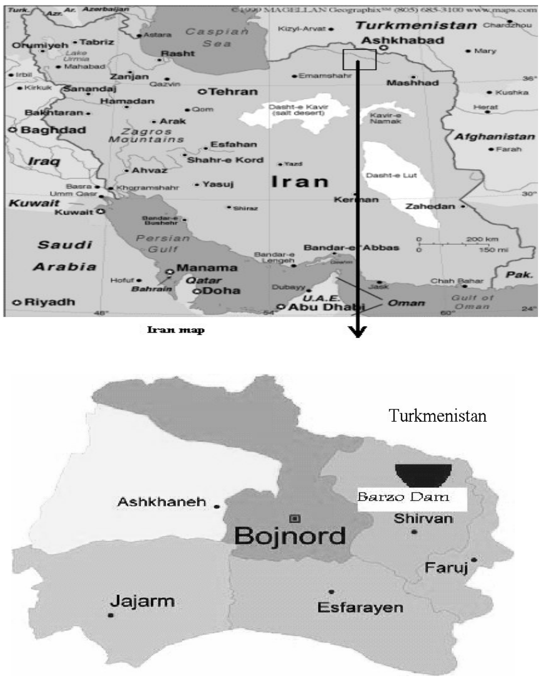

Figure 1. North Khorasan Province and Iran maps.

statistical population of this study, thereby the villages formed the first stratum of the stratum sampling with the second stratum being the farmer level, where 200 farmers were randomly selected in 2005 and obtained the essential information and data through filled up questionnaires in year 2005. Since all the farmers were among small scale groups of farmers (less than three ha^{-1}) and there were no significant differences observed among them, therefore the farmers were grouped into subsets of similar crop distribution and constraint levels to avoid and limit the effect of aggregation bias.

METHODOLOGY

The principle of maximizing the total economic value of a resource such as water is an essential concept of modern natural resource economics. In this study, Linear Programming (LP) and MultipleG Linear Programming (MGLP) models were employed to estimate the economic value and optimal allocation of water as well as optimal cropping pattern in the districts.

Linear Programming Model (LP)

Objective Function of LP

The objective function of LP model is to maximize total net return from all crops in all the lower part lands of the Shirvan Barzo (SB) Dam. The net return is computed by subtracting the total cost of crops except water cost from total income of cropping activities of farmers in any region. Thus the objective function used in this study is as follows:

$$Maximize \quad \sum_{j=1}^{3} \sum_{i=1}^{14} G_{ij} X_{ij} \qquad (1)$$

Where G_{ij} is the net return from ith crop (IRR ha^{-1}) in jth region and X_{ij} is the planted acreage of ith crop in jth region. The *ith* is the relevant variable for cultivable crops in three regions of lower part lands of SB Dam, in which i= 1, 2, 3,…, 14 representing the crop of wheat, barley, corn, sugar beet, sunflower, onion, potato, cucumber, tomato, alfalfa, grape, apple, apricot and walnut respectively, and *jth* stands for the three regions, *j*=1, 2, 3 representing GOL, ZIA and SEY respectively. Therefore, in each region, the net return for each *i*th crop would be different.

Linear Programming Constraints

Land area constraint

Land area constraints were divided into three groups. The first is concerned with yearly crops, the second is concerned with the permanent crops and the third with the second harvest crops. These constraints were introduced into the models as follows:

1. Land area constraint of yearly crops:

$$\sum_{i=1}^{9} X_{ij} - TX_j \leq 0 \qquad \textit{For j= 1, 2, 3} \qquad (2)$$

Where TX_j is the total cultivable lands in *j*th region.

2. Land area constraint of permanent crops:

$$\sum_{i=10}^{14} X_{ij} - TX_j \leq 0 \qquad \textit{For j= 1, 2, 3} \qquad (3)$$

$$\sum_{i=10}^{14} X_{ij} - TXB_j \geq 0 \qquad \textit{For j= 1, 2, 3} \qquad (4)$$

Where TXB_j is current acreage of orchard crops in *j*th region.

3. land area constraint of second harvest crops:

$$XM_j - \sum_{i=1}^{2} X_{ij} \leq 0 \qquad \textit{For j= 1, 2, 3} \qquad (5)$$

Where XM_j is the planted acreage of summer crops such as cucumber (second harvest crop) in *j*th region.

Monthly water availability constrain

Since the timing of cultivation, water requirement of the crops and amount of water available are different in any month of the year, it is essential for the water constraint to be monthly considered as follows:

$$\sum_{i=1}^{14} W_{ijk} X_{ij} - TW_{jk} \leq 0 \qquad \textit{For j= 1, 2, 3} \quad (6)$$

$$\sum_{j=1}^{3} TW_{jk} - TW_k <= 0 \qquad \textit{For j= 1, 2, 3} \quad (7)$$

$$\sum_{k=1}^{10} TW_k - TW <= 0 \qquad \textit{For j= 1, 2, 3} \quad (8)$$

Where W_{ijk} is water requirement for *i*th crop (m^3 ha^{-1}) in *j*th region and *k*th month, TW_{jk} is the total water allocated to *j*th region in *k*th month, TW_k is the total exited water from SB dam in *k*th month and *TW* is the total allocable water from SB dam in one year. Item *k* stands for irrigation months namely, *k* =1, 2, 3,…,10 representing the months of the April, May, June, July, August, September, October, November, December and winter respectively.

Calculations of the irrigation water requirements have carried out through by FAO's CROPWAT software that was used to compute the net irrigation water requirement for each crop in the areas and then through division by the water efficiency of the areas, the gross irrigation water requirement is obtained and can be expressed in CM ha^{-1}.

According to the above mentioned equations in LP, the model can optimize the total available water behind dams throughout different seasons of the year and throughout different regions across dam sites. In this model surplus water from any one month can be carried over to another.

Seasonal labor constraint

The labor requirement constraints in different regions are as follows:

$$\sum_{i=1}^{14} L_{ijs} X_{ij} - TL_{js} \leq 0 \qquad \text{For j= 1, 2, 3} \quad (9)$$

Where L_{ijs} is the labor requirement of *i*th crop in *j*th region and *s*th season (man-day ha^{-1}) and TL_{js} is the total current labor of *j*th region in *s*th season.

Fertilizer and pesticide constraint

Since the production and distribution of such subsidized inputs as chemical fertilizers and pesticides are limited in Iran, fertilizer and pesticide constraints are considered as follows:

[DOR: 20.1001.1.16807073.2011.13.4.11.0]

$$\sum_{i=1}^{14} F_{cij} X_{ij} - TF_{cj} \leq 0 \quad c= 1, 2,..., 5 \; j= 1, 2, 3 \quad (10)$$

Where F_{cij} represents the amounts of *c*th fertilizer and pesticide requirement of *i*th crop in *j*th region (kg ha^{-1}) where *c= 1, 2,..., 5* stands for Phosphate, Nitrogen, potassium animal manure, and pesticides, respectively. TF_{cj} stands for total *c*th fertilizer available and pesticide in *j*th region.

Machinery constraint

Since farmers attempt to use such agricultural machinery as tractors, combines and harvesters for important activities in the peak periods, thus machinery constraint is considered as follows:

$$\sum_{i=1}^{14} M_{mij} X_{ij} - TM_{mj} \leq 0 \quad m= 1, 2, 3 \; for \; j= 1, 2, 3 \quad (11)$$

Where M_{mij} is the *m*th machinery time requirement of *i*th crop in *j*th region (hour ha^{-1}) in which *m= 1, 2* and 3 stand for tractor, combine and other harvester respectively. TM_{mj} representss the total *m*th machinery capacity in *j*th region.

Crop rotation constraint

Various crop rotations employed in this area are as follows:

1. Cereal, melon-bed, cereal, cereal, sugar beet
2. Sugar beet, cereal, alfalfa
3. Corn, cereal, sugar beet

In order to consider crop rotation in LP model, the farm is divided into equal sections for the various crops to be cultivated and total acreage of any crop is fixed yearly. Thus the crop rotation constraint equations are as follows:

1. First rotation equation:

$$\sum_{i=1}^{2} Y_{i1r} + \sum_{i=5}^{9} Y_{i2r} + \sum_{i=1}^{2} Y_{i3r} + \sum_{i=1}^{2} Y_{i4r} + Y_{45r} - 5TY_r = 0$$

For r= 1 (12)

Y_{i1r},…, Y_{i4r} are the planted acreage of *i*th crop in first, …, fourth year in *r*th rotation and TY_r is the planted acreage of any rotation piece in *r*th rotation.

2. Second rotation equation:

$$Y_{41r} + \sum_{i=1}^{2} Y_{i2r} + Y_{103r} - 3TY_r = 0 \quad For \; r=2 \quad (13)$$

3. Third rotation equation:

$$Y_{31r} + \sum_{i=1}^{2} Y_{i2r} + Y_{43r} - 3TY_r = 0 \quad For \; r=3 \quad (14)$$

4. Sum planted acreage of any crop in various rotation equations:

$$\sum_{r=1}^{3}\sum_{t=1}^{5} Y_{itr} - X_i = 0 \quad For \; i= 1, 2,…, 14 \quad (15)$$

$$X_i - \sum_{j=1}^{3} X_{ij} = 0 \quad For \; i= 1, 2,…, 14 \quad (16)$$

Y_{itr} is the planted acreage of *i*th crop in *t*th year in *r*th rotation.

5. Sum of total rotation equation:

$$5TY_1 + 3TY_2 + 3TY_3 - \sum_{j=1}^{3} TXZ_j = 0 \quad (17)$$

Self sufficiency constraint

The acreage of wheat and barley necessary to meet farmers' seed and his animal' needs was determined, for self sufficiency, to be 48, 101 and 31 ha for wheat and 37, 80 and 27 ha for barley in GOL, ZIA and the SEY areas, respectively, which is called TXK_j as the total planted acreage of all crops in *j*th region for self-sufficiency.

Cash working capital constraint

Since farmers' incomes are limited and, various crops compete with each other for access to the working capital so the cash working capital constraint is considered as follows:

$$\sum_{i=1}^{14} I_{ij} X_{ij} - TI_j \leq 0 \quad For \; j= 1, 2, 3 \quad (18)$$

Where I_{ij} is the cash working capital of *i*th crop in *j*th region (IRR ha^{-1}) and TI_j is the total cash working capital available in *j*th region.

Multiple Goals Linear Programming Model (MGLP)

In lexicographic MGLP model where there is a hierarchy of priority levels for goals, such a case arises when one or more of the goals are clearly far more important than the others. Thus, the initial focus should be on achieving these first-priority goals as far as possible. The other goals might naturally be

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divided further into second-priority goals, third-priority goals, and so on.

After finding an optimal solution with respect to the first-priority goals, one can break any tie by considering the second-priority goals. Following this optimization any tie that remains can be eliminated by considering the third-priority goals, and so on. Based on LP modeling, at the first stage of solving a LMGLP problem, the only goals included in the model are the first-priority ones. Then one prepares to break the tie among the solutions by moving to the second stage and adding the second-priority goals to the model but then one also adds the constraint that the first-stage objective function equals *Z** (objective function). Later, one repeats the same process for any lower priority goals. In LMGLP models a goal is optimized when the last targets are in their the optimal level, in other words, to reach the second target one cannot move away from the first target before its optimization.

Weighted MGLP model has an objective function with different weights of deviation from all targets that have been estimated via Analytic Hierarchy Process (AHP) method.

Objective Function of MGLP

The objective function in MGLP model is the minimization of the total deviations from goals as follows:

$$Min \sum_{r=1}^{6} w_r (d_r^+ - d_r^-) \quad (19)$$

Where w_r represents the weight of *r*th goal, d_r^- and d_r^+ are the negative and positive deviations of *r*th goal. Based on information collected from government policy makers and from farmers, the priority of goals is classified in four levels as follows:

First level: To develop the acreage of orchard crops (developmental goal)

Second level: To increase net return of farmers (economical goal)

Third level: To increase the employment level in the region (social goal)

Forth level: To lower the use of fertilizers and pesticides (environmental goal).

Goal Programming Constraints

Development Goal Constraint

The developmental goal (GXB) is to increase the orchard crops acreage by 20 percent as according to the following equation:

$$\sum_{j=1}^{3} \sum_{i=11}^{14} X_{ij} + d_r^- - d_r^+ \geq GX\ B \qquad For\ \ r=\ 1 \quad (20)$$

Economic Goals Constraint

The economic goals are as follows:

$$\sum_{j=1}^{3} \sum_{i=1}^{14} G_{ij} X_{ij} + d_r^- - d_r^+ \geq GG \qquad For\ \ r=\ 2 \quad (21)$$

$$\sum_{j=1}^{3} \sum_{i=1}^{14} I_{ij} X_{ij} + d_r^- - d_r^+ \leq GI \qquad For\ \ r=\ 3 \quad (22)$$

Where GG is the achievable goal level of net return (increase the in total farmer net return by 25 percent) and GI the achievable goal level of ideal production cost (decrease the production cost by 10 percent)

Based on the four mentioned goals, Table 1 illustrates the deviations of each of the goals.

Social Goal Constraint

The social goal is considered as follows:

$$\sum_{j=1}^{3} \sum_{i=1}^{14} \sum_{m=1}^{4} L_{ijm} X_{ij} + d_r^- - d_r^+ \geq GL \quad For\ r=\ 4 \quad (23)$$

Table 1. Various goal values based on increase of α percent over the current situation and the estimated weights by AHP.

Goal No.	r=1	r=6	r=5	r=4	r=3	r=2
α percent	-0.15	-0.15	0.3	-0.10	0.25	0.2
Deviation variable	d_6^+	d_5^+	d_4^-	d_3^+	d_2^-	d_1^-
weights by AHP	0.12	0.16	0.17	0.17	0.18	0.20

Where GL is the achievable goal level of ideal employment (increase in the employment level by 30 percent)

Environmental Goals Constraint

Since an increase in the use of chemical fertilizers and pesticides is the main source of non-point source pollution in agriculture, the area authorities consider the following environmental goals:

$$\sum_{j=1}^{3}\sum_{i=1}^{14} k_{ij} X_{ij} + d_r^- - d_r^+ \le GF \qquad \text{For } r=4 \ (24)$$

$$\sum_{j=1}^{3}\sum_{i=1}^{14} s_{ij} X_{ij} + d_r^- - d_r^+ \le GS \qquad \text{For } r=6 \ (25)$$

Where GF and GS are the achievable goal levels of the total use of the chemical fertilizers and pesticides (decrease the total use of chemical fertilizers and pesticides by 15 percent)

Table 1 shows the various goal values that are based on increase of α percent to the amount of current situation in LMGLP model and the estimated weight of any target *via* AHP in WMGLP model.

RESULTS AND DISCUSSION

Table 2 shows yield, price, variable production cost, applied water, labor, chemical fertilizers and pesticide inputs that are used for crops in three areas in the lower part lands of SB Dam. The net returns are computed by multiplying the yield by price and subtracting the variable production costs except water charges. In this study the models are solved through Lindo Software with 75 decision variables and 130 constraints with the essential results presented.

Table 3 shows considerable difference between the monthly allocation volumes of water by the SB Dam used in the current situation and the volume of the optimal monthly allocation of water according to the LP, LMGLP and WMGLP models. Based on the optimal allocation of the LP, LMGLP and WMGLP models, the highest level of the SB dam's water allocation occurred during July with 9.89 MCM in LP model and 10.06 MCM according to LMGLP model and 9.12 MCM according to WMGLP model while the least occurred during December with 0.02 MCM. The results in this table show that in the optimal allocation models, the total applied water is decreased by 19 percent as compared with the current situation.

Based on the results of monthly optimal allocation of water (Table 3), the volumes of optimal water allocation of SB Dam to the three areas are shown in Table 4. Based on the LP model, the monthly allocated water to GOL area is decreased in April, May, September and winter while being increased in the other months. In ZIA area, the monthly allocated water is decreased in all months except in December as well as in winter compared to the present condition. In SEY area, the monthly allocated water is decreased in April, May, September, October and November while increased in the other months compared to the present situation. In addition, based on the LMGLP and WMGLP models the monthly allocated water to GOL, ZIA and SEY areas are shown in Table 4 (columns 7 and 10) and interpreted as done for LP model.

In total, based on the LP model, the volume of the annually allocated water to GOL and SEY areas are increased by 12 and 5 percent in excess to the present conditions, whereas the volume of the annual allocated water to ZIA area is decreased by 42 percent. In addition, based on the LMGLP and WMGLP models, the volume of the annually allocated water to GOL, ZIA and SEY areas are presented in Table 4 and interpreted as done for the LP model.

Based on the results of the economic value of water as in Table 4, in the GOL area, throught performing the optimal cropping pattern as based on LP, LMGLP and WMGLP methods, the maximum economic values of water belong to winter, April and July which are 179, 1,240 and 252 Rials respectively. In the ZIA area by performing the optimal cropping pattern as based on LP, LMGLP and WMGLP methods, the maximum economic values of water belong to August, April and November which are 629, 635 and 242 Rials respectively. In the SEY area by performing the optimal cropping pattern as based on LP, LMGLP and WMGLP methods, the

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Table 2. Net return, production cost and inputs in different areas (IRR= Iranian Rials and CM= Cubic Meter).

Area	Crop	Yield	Price	Production cost	Applied water	Labor	Chemical fertilizer	Pesticide
		(kg)	(Rials)	(Million IRR)	(CM)	(Man-day)	(kg)	(kg)
Gol area	Wheat	2880	2850	3.356	6862	30.8	212	4
	Barley	2820	1950	2.639	6611	28.8	233	1
	Corn	6250	2000	3.107	14313	65.1	560	1
	Sugar beet	32500	350	5.751	19265	54.6	882	6
	Sunflower	1200	10000	6.802	8160	104.2	700	0
	Onion	28750	1200	6.802	6235	104.2	700	0
	Potato	27550	850	8.670	10358	109.7	426	3
	Spring cucumber	15500	1200	1.948	12131	31.5	233	0
	Fall cucumber	15500	1200	7.143	14487	99.4	724	12
	Tomato	35520	1480	12.728	13375	88.9	443	4
	Alfalfa	5500	1250	3.250	22024	57.0	650	0
	Grape	7750	2900	12.200	12464	156.0	1070	71
	Apple	12500	1500	5.850	17856	72.0	770	12
	Apricot	3750	2500	7.250	15087	100.0	575	11
	Walnut	2650	1150	12.000	17097	99.0	420	12
ZIA area	Wheat	2050	2850	3.304	7004	22.7	271	3
	Barley	1430	1950	2.475	7004	22.9	209	2
	Corn	5520	2000	5.872	20763	65.1	461	0
	Sugar beet	27000	350	5.016	15716	59.0	486	6
	Sunflower	1000	16100	9.381	7451	115.2	922	7
	Onion	25750	1200	9.381	5976	115.2	922	7
	Potato	23330	850	7.914	9000	140.8	1083	13
	Spring cucumber	10750	1200	1.847	17401	31.5	233	0
	Fall cucumber	10750	1200	7.071	22540	99.1	724	12
	Tomato	27780	1480	9.788	12598	106.7	2000	3
	Alfalfa	5000	1250	3.750	18920	59.0	670	0
	Grape	7250	2900	7.250	10625	146.0	1020	65
	Apple	11850	1500	5.450	14027	69.0	855	12
	Apricot	3550	2500	8.250	12595	97.0	525	13
	Walnut	2530	1150	8.200	11922	91.0	945	9
SEY area	Wheat	1830	2850	3.133	7333	27.2	342	3
	Barley	3610	1950	3.058	7333	31.0	497	4
	Corn	6850	2000	0.726	14831	26.9	651	1
	Sugar beet	30000	350	6.715	18093	77.8	186	0
	Sunflower	1330	8459	5.633	6911	91.7	750	0
	Onion	30000	1200	5.633	5425	91.7	750	0
	Potato	26500	850	9.927	8627	101.4	395	2
	Spring cucumber	15000	1200	2.864	12429	48.3	167	0
	Fall cucumber	15000	1200	2.622	16100	60.9	0	0
	Tomato	35500	1480	9.954	11424	98.2	802	7
	Alfalfa	6120	1250	3.500	16844	70.0	610	0
	Grape	8200	2900	12.500	11173	148.5	860	67
	Apple	12500	1500	5.450	14549	64.4	700	11
	Apricot	3830	2500	8.250	11364	99.5	405	11
	Walnut	2600	1150	8.200	15175	96.1	800	8

[DOR: 20.1001.1.16807073.2011.13.4.11.0]

Table 3. Monthly optimal allocation of water, in SB Dam

Months of The year	Current Situation (MCM)	LP Model Volume (MCM)	LP Model Change (Percent)	LMGLP Model Volume (MCM)	LMGLP Model Change (Percent)	WMGLP Model Volume (MCM)	WMGLP Model Change (Percent)
Apr	1.55	0.76	-51	0.76	-0.51	0.76	-0.51
May	4.62	2.97	-36	3.14	-0.32	3.27	-0.29
Jun	9.83	8.06	-18	8.44	-0.14	8.09	-0.18
July	10.10	9.89	-2	10.07	0	9.12	-0.10
Aug	9.39	7.76	-17	7.54	-0.20	7.84	-0.17
Sep	6.48	4.61	-29	4.36	-0.33	5.27	-0.19
Oct	2.84	2.21	-22	1.94	-0.32	1.90	-0.33
Nov	0.89	0.70	-21	0.71	-0.20	0.72	-0.19
Dec	0.02	0.02	0	0.02	0	0.02	0
Winter[a]	0.05	0.05	0	0.02	-0.6	0.02	-0.6
Total	45.76	37	-19	37	-0.19	37	-0.19
Apr	1.55	0.76	-51	0.76	-0.51	0.76	-0.51

[a] Because of a little demand of water in January, February and March. The aggregate water demand is indicated as winter.

maximum economic values of water belong to July, July and September, amounting to 898, 1,296 and 403 Rials respectively. The results in Table 4 show that the economic value of water is far higher than the paid charges (35 Rials per cubic meters) for water by farmers, causing waste of water in agriculture sector.

Table 5 compares the present and optimal cropping pattern for GOL, ZIA, and SEY areas in terms of agronomy- horticulture as by using LP, LMGLP and WMGLP models. Based on LP model it is suggested that the irrigated wheat, corn, autumnal cucumber and sunflower should be cultivated in GOL area; irrigated wheat, irrigated barley, sugar beet, autumnal cucumber and tomato in ZIA area; and irrigated wheat, irrigated barley, corn and tomato in SEY area. Based on LMGLP and WMGLP model the optimal cropping pattern for GOL, ZIA and SEY are shown in Table 5 too.

LP, LMGLP and WMGLP models suggest that in GOL area, walnut acreage should be increased in addition to agronomy crops from 11 to 117.4, 125.4 and 125.9 hectares respectively, in order to maximize profits in this area.

Since the self-sufficiency and stable current horticultural acreage constraints are considered in the models, thus some agricultural operations like irrigated wheat, irrigated barley, alfalfa and horticultural crops are entered into the optimal cropping pattern, whereas these activities are not economically profitable. But increasing the irrigated wheat acreage more than self-sufficiency level shows the profitability of this cropping pattern.

Table 5 also shows the percentage of the total net rerun change of areas in LP, LMGLP and WMGLP models as compared with the current situation. As shown, performing the optimal cropping pattern increases the total net return of GOL area by 30, 33.3 and 29.2 percent in LP, LMGLP and WMGLP models respectively, decreases the total net return of ZIA area by 30, 36.8 and 51 percent in LP, LMGLP and WMGLP models respectively, while increasing the total net return of SEY area by 37.6, 32.9 and 31 percent in LP, LMGLP and WMGLP models respectively. These results show that farmers who cultivate in SEY, GOL and ZIA areas have less efficiency in optimal allocating of resources respectively as compared with the optimal cropping pattern of LP, LMGLP and WMGLP models, so the net return of farming activities in the present condition is less than that in the optimal cropping pattern conditions. Therefore the farmers in ZIA area perform almost optimally in comparison with those in the other areas. The main reason for the increase in the net return in LMGLP and WMGLP

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Table 4. Economic value and optimal allocation of SB dam water in the GOL, ZIA and SEY areas.

	Months	Current	LP model			LMGLP model			WMGLP model		
Area	Of	Situation	Volume	Change	Economic value	Volume	Change	Economic value	Volume	Change	Economic value
	Year	(MCM)	(MCM)	(Percent)	(Rials)	(MCM)	(Percent)	(Rials)	(MCM)	(Percent)	(Rials)
GOL area	Apr	0.50	0.39	-22	179	0.41	-19	1240	0.41	-19	107
	May	1.23	1.18	-4	307	1.33	8	216	1.31	6	107
	Jun	2.14	2.58	20	307	3.09	44	764	2.98	39	107
	July	2.25	3.13	39	740	3.62	61	216	3.44	53	252
	Aug	2.34	2.47	6	307	2.42	3	216	2.31	-1	107
	Sep	1.60	1.52	-5	677	1.37	-14	216	1.35	-16	107
	Oct	0.74	0.80	8	578	0.81	9	216	0.81	9	107
	Nov	0.29	0.33	17	307	0.34	19	554	0.34	19	246
	Dec	0.00	0.00	0	307	0.00	0	216	0.00	0	107
	Winter	0.05	0.03	-43	835	0.02	-57	216	0.02	-57	107
	Total	11.14	12.44	12	-	13.41	20	-	12.96	16	-
ZIA area	Apr	0.79	0.28	-64	307	0.27	-66	635	0.27	-66	107
	May	2.44	1.10	-55	343	1.01	-58	216	0.89	-64	107
	Jun	5.54	2.78	-50	307	2.63	-53	216	1.91	-65	107
	July	5.62	3.46	-38	307	3.09	-45	551	1.97	-65	107
	Aug	5.39	3.31	-39	629	2.53	-53	216	1.96	-64	107
	Sep	3.69	2.34	-36	307	1.65	-55	529	1.61	-56	107
	Oct	1.54	1.22	-21	307	0.94	-39	216	0.91	-41	107
	Nov	0.43	0.29	-33	307	0.29	-33	216	0.30	-31	242
	Dec	0.01	0.01	0	307	0.01	0	216	0.01	0	107
	Winter	0.00	0.00	-	307	0.00	-	216	0.00	-	107
	Total	25.44	14.79	-42	-	12.41	-51	-	9.81	-61	-
SEY area	Apr	0.25	0.08	-67	343	0.08	-67	792	0.08	-67	107
	May	0.95	0.69	-28	307	0.79	-17	216	1.08	13	107
	Jun	2.16	2.70	25	307	2.73	27	216	3.21	49	139
	July	2.23	3.30	48	898	3.35	50	1296	3.70	66	107
	Aug	1.76	1.98	13	307	2.60	48	216	3.57	103	107
	Sep	1.20	0.74	-38	307	1.34	12	216	2.31	93	403
	Oct	0.56	0.20	-65	505	0.20	-65	788	0.19	-66	107
	Nov	0.17	0.08	-53	307	0.08	-53	216	0.08	-53	107
	Dec	0.00	0.00	-	307	0.00	-	216	0.00	-	107
	Winter	0.00	0.00	-	307	0.00	-	216	0.00	-	107
	Total	9.28	9.77	5	-	11.18	21	-	14.22	53	-

Table 5. Optimal cropping pattern and total net return of GOL, ZIA and SEY areas in different models (hectares and million Rials).

Crop	GOL area				ZIA area				SEY area			
	Current	LP	GP Models		Current	LP	GP Models		Current	LP	GP Models	
	Situation	Model	LGP	WGP	Situation	Model	LGP	WGP	Situation	Model	LGP	WGP
Irrigated Wheat	156.8	78.8	48	48	555.2	101	101	101	234.2	31	31	31
Irrigated Barley	53.9	0	37	37	190.9	80	80	80	80.5	27	27	27
Corn	39.2	23.7	10.1	0	138.8	0	0	0	58.6	9.3	9.3	0
Sugar beet	73.5	0	0	0	260.3	235.2	71.5	0	109.8	0	0	0
Spring cucumber	24.5	0	23	0	86.6	0	128.5	0	36.7	0	189.4	0
Fall cucumber[a]	35	78.8	0	0	90	128.5	0	0	40	0	0	0
Tomato	24.5	0	0	0	86.8	150.7	150.7	0	36.6	578	172.1	0
Sunflower	9.8	263.9	371.1	361.1	34.7	0	0	0	14.6	0	0	0
Onion	9.8	0	0	0	34.7	0	0	0	14.6	147.3	371.2	742
Potato	49	0	0	0	173.5	0	0	0	73.2	0	0	0
Alfalfa	49	49	49	49	173.5	173.5	173.5	173.5	73.2	73.2	73.2	73.2
Grape	217.8	217.8	217.8	217.8	236.8	236.8	236.8	236.8	22.9	22.9	22.9	22.9
Apple	110	110	110	110	119.5	119.5	119.5	119.5	21.7	21.7	21.7	21.7
Apricot	6.2	6.2	6.2	6.2	6.8	6.8	6.8	73.8	1.2	1.2	1.2	1.2
Walnut	11	117.4	125.4	125.9	11.9	11.9	11.9	11.9	2.2	2.2	2.2	2.2
Total cultivated (ha)	835	835	835	835	2110	1244	1080	797	780	780	780	780
Acreage change (percent)	0	0	0	0	0	-41	-48.8	-62.2	0	0	0	0
Total net return (Million Rials)	6147.8	7991.7	8195.6	7941.4	11633.7	8139.2	7348	5695.4	4109.5	5654	5460.8	5381.6
Net return change (Percent)	0	30	33.3	29.2	0	-30	-36.8	-51	0	37.6	32.9	31

[a] This crop is cultivated after irrigated wheat and irrigated barley crops (Second harvest crop).

models to be less than that in the LP model is because of multiple goals being factored into these models.

Based on the total net return change of the three models, it is estimated that the LGP model is the best for GOL area and LP model is the best one for ZIA and SEY areas. According to the results obtained in this research, there are some recommendations to be made as follows:

1- Based on water shortage and the economic value of the expanding walnut crop, it is suggested to expand this horticultural product within the water limitations outlined in the study.

2- Since the results of optimal allocation show that the applied water in optimal models has been decreased so the area decision makers and policy makers can manage the allocation of water as based on optimal models.

3- Making the water pricing policy in line with the economic value of water would motivate farmers to economize in their water use. To implement and fulfill this policy, farmers should actively participate in plannings and in performing the tasks, and they should be motivated to adjust themselves to the new conditions too.

4- To implement optimal pricing policies, it is suggested that an agricultural water association be established by the farmers, who will own, manage and monitor it to maintain the optimal water price and to spend the incoming revenues to improve water resources.

5- The optimal allocation of the SB Dam water to the areas and use of water for irrigating the economically viable crops not only maximizes net return to each area and to the lower part lands of SB Dam as a whole, but it also results in the economization of water use. Therefore, in order to monitor the optimal allocation of the water to each area, it is suggested that water counters be installed at farms' entrances to measure the exact volumes of water used by farmers as clients.

CONCLUSIONS

The main results of this research are:

1- The optimal cropping pattern as based on LP, LMGLP and WMGMP models in GOL area suggest expanding the walnut acreage from 11 hectares of the present situation to 117.4, 125.4 and 125.9 hectares respectively.

2- Performing the optimal cropping pattern based on LP, LMGLP and WMGMP method will increase the total profit of GOL area by 30, 33.3 and 29.2 percent respectively and will increase the total profit of SEY area by 37.6, 32.9 and 31 percent respectively, while decreasing the total profit in ZIA area by 30, 36.8 and 51 percent respectively.

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تخصیص بهینه اقتصادی آب کشاورزی: رهیافت برنامه ریزی ریاضی

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چکیده

بکارگیری مدیریت بر مبنای تقاضای آب در تعیین ارزش اقتصادی آب یکی از موضوعات مهم مدیریت منابع آب می باشد، که در این راستا مطالعه حاضر به تخصیص بهینه آب کشاورزی، تعیین ارزش اقتصادی آب و تعیین الگوی کشت بهینه اراضی پایاب سد بارزو شیروان در استان خراسان شمالی می پردازد. در این مطالعه با استفاده از روش برنامه ریزی خطی معمولی (LP) و برنامه ریزی خطی چند هدفه (MGLP) به حداکثرسازی سود کشاورزان منطقه پرداخته شده است. اهداف مختلف در روش برنامه ریزی خطی چند هدفه شامل اهداف توسعه ای، اجتماعی، اقتصادی و زیست محیطی می باشند که بترتیب دارای بالاترین اولویت برای کشاورزان منطقه می باشند. نتایج این مطالعه نشان می دهد که اجرای الگوی کشت بهینه و تخصیص بهینه آب کشاورزی اثرات قابل توجهی در سود کشاورزان منطقه داشته و میزان آب مصرفی را ۱۹ درصد کاهش داده است. ارزش اقتصادی هر واحد منبع آب کشاورزی نیز بین ۱۰۷ الی ۱۲۹۶ ریال برآورد گردیده است. بر اساس نتایج این مطالعه پیشنهاد می گردد که از مدلهای بهینه برای تخصیص آب بین مناطق مختلف استفاده نموده و در راستای افزایش انگیزه کشاورزان جهت کاهش مصرف آب نیز قیمت گذاری آب در سطح ارزش اقتصادی آن صورت گیرد.

[DOR: 20.1001.1.16807073.2011.13.4.11.0]