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Application of Mathematical Programming Model for Optimal Allocation of Voshmgir Dam Water for Various Consumptions (Case Study: Golestan Province)

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Abstract Water is an essential yet constrained commodity for human communities and ecological systems depend on it. With population growth and economic development, water resource is increasingly declining. Over the past two decades, because of changes in population and climate, and relative welfare increase, the per capita consumption of water has increased. Thus, optimal use of available water resources is inevitable. In this study, a mathematical programming model for optimal allocation of water among the sectors of agriculture, aquaculture and environment is used. The data for the study were collected from Golestan Regional Water Organization which related to the years of 2001 to 2013. The results showed that under the efficiencies of 37, 45 and 51 percent during the three-year planning horizon, the amount of water allocated to agriculture decreases, water allocation to the environment increases and water allocation to the aquaculture sector will remain unchanged. The acreage of some crops under these efficiencies will not change.

Keywords: Water Allocation, Optimal Cropping Pattern, Linear Programming, Voshmgir Dam.

1 Introduction

Humans have long sought to control water as their first need. With the passage of time and social, economic and industrial advancements, the amount of demand for water also increased and the need of programming for this vital element has been made clearer. In the meantime, the drought and famine in the country is a geographical fact. Therefore, to mitigate the negative effects, a suitable strategy should be looked for. Available water resources do not fully meet the water requirement of plants during drought; therefore, crops will suffer from water stress and will eventually diminish yield. Consequently, it is necessary to optimize the

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water use and the allocation of existing water resources among different plants to minimize the adverse effects of water deficit [1]. Also in water resource management, it is tried to design water resource systems such that different purposes such as hydroelectric power generation, drinking and agriculture water supply, destructive flood control, fishing, shipping, recreation and industry optimally be provided due to the constraints. In this regard, the use of mathematical programming models has a special place.

Although agriculture is the largest consumer of renewable water resources in the country, agricultural production from it is low. Therefore, any attempt to conserve water consumption is vital [2]. According to the existing data and studies performed in Iran, we can say that water is most scarce factor in agricultural production and development of the agriculture sector is directly related to the quantity and quality of water resources and how to manage and use these resources [3]. Therefore, water management and proper use of water resources, due to having an efficient and crucial role in the sustainable development of the country, must be done with a consistent programming [4]. Constrained water resources, increasing population, economic growth, and consequently increasing demands in various fields have created a critical condition for water resources that Golestan province is not except from it.

Mathematical models are used as a tool for achieving the goals of managers and resorvoir systems planners. Meanwhile, simulation models are the most widely used models which anticipate system response to a specific policy using series of physical theories and rules related to reservoir operation[5].

One of the most important debates on management of water resources is determining the reservoirs optimal policies. Since the late 50s and especially early 60s, a lot of water resources researches have been conducted on this issue. Natural systems of catchment regions and reservoirs despite their simple appearance have great complexity. So that, they can be considered as the most complex systems in engineering. This complexity is mainly the result of random and uncertain variables involved in these systems [6]. Many studies have been performed on the operation of reservoir systems by optimization, simulation or both methods. The optimization method has been considered in this study. In the following some studies in this field are mentioned. Optimal allocation of water reservoirs is considered as one of the most important aspects of water resources management In the following some studies in this field are mentioned.

Ghorbani et al. used linear programming on the water allocation of Maroon and Jereh reservoir dams. Because of the importance of multiple purposes of dams and the parallelism of the above dams, both reservoirs including Aala River were modeled systematically and integrated with monthly time steps. In this study, 5040 variables and 2520 constraints during the 30-year period were studied. The results showed that due to the use of linear relationships in the reservoir policy, linear programming can bring good results[7].

Najafi et al. used linear programming for the optimal operation of Voshmgir Dam. The results showed that reservoir operation policy under normal and current conditions only can meet the requirements in the rainiest months and the driest months are critical months for water consumption. Also in this policy, no management was applied on potential floods and strong overflows are seen in a number of statistical months and years. The reservoir storage amount was estimated about 17 percent more than the current reservoir operation methods using linear programming; as a result, the operation of this method was more than the current operation condition[8].

Ghadami et al developed a definitive genetic algorithm model for optimal operation of single-purpose, water resources, multi-reservoir system in the north of Khorasan for agricultural purposes. The main goal is to maximize the gross profit arising from planting all the plants in a chosen planting pattern[1].

Sabouhi et al. studied the optimal allocation of Torogh dam water between the urban and agricultural uses using a fuzzy two-stage, interval-parameter, multi-stage, stochastic programming under uncertainty. The results showed that agricultural profit is more sensitive to water allocation. They also found that in 66% of the cases urban consumers and in 18% of the cases both consumers suffer from water shortages[9].

Mosnen Mozaffari investigated Amirkabir dam water management using the decision support model. In this study, decision support was done using the two methods of linear programming and goal programming. The results showed that acreage in linear programming is more than goal programming but more water is allocated to drinking section in goal programming and due to the primary purpose of the dam which is supplying water to Tehran city, goal programming offers better results to decision makers. In addition, using the model and changing its data at any period, the amount of water allocated to each section can be determined[10].

Habibi Davijani et al. offered a model for optimal allocation of water resources among agriculture, industry and services sections. Then using Genetic Algorithm Particle Swarm Optimization (GAPSO)*, simulation of the objective function and optimal allocation of water resources were conducted between agriculture and industry sections. According to the results of allocation, it can be noted that deficit irrigation patterns, cropping pattern change, eliminating the cultivation of some products and using more water resources in the field of industry can be influential in boosting the revenues to 114 billion Riyals [11].

Amini Faskhoudi and Noori determined the cropping pattern of Southern Baraan rural region in the east of Esfahan Province based on operation optimization of water and soil resources using mathematical programming nonlinear patterns. In order to incorporate environmental, economic and social dimensions, two criteria of maximum net return and employment creation per unit of agricultural water consumption were defined as sustainability indicators of the system. Thus, the ratios of "net return / water consumption" and "employment / water consumption" were optimized by using single and multiple objective fractional programming models [12].

Etkin et al. used a random programming to improve the operation of multi-reservoir system in Burkina Faso in East Africa. A network of these reservoirs and diversion structures provide the water needed for urban regions and agricultural products irrigation. Due to the variable nature of rainfall, inflows to the reservoir of this region were divided into two parts of seasonal and annual sections. In accordance with the scenarios conducted in this study, predictions of seasonal rainfall may offer more effective free decision making to different stakeholders in the region[13].

Li et al. used Interval Parameter, Multi-stage, Stochastic Programming (IMSLP) for water resources management in Canada under different scenarios. In addition to the allocation of water among different consumptions, they investigated the exchange between environmental and economic objectives. Their results were presented in 81 scenarios for the three consumers of municipal, agricultural, industrial and over three future periods[14].

Vadula et al. developed the common operation model for irrigation purposes for the combination of different products in Karnataka state of India. The model was used for a system which consists of a reservoir, canal and aquifer. Objective function was considered maximizing the sum of products relative production under the three constraints of mass

* . Genetic Algorithm Particle Swarm Optimaization

balance in the reservoir, soil moisture balance for each product and the equations of ground water flow. With this model, the best operation pattern of reservoir, groundwater pumping and water allocation to the products during different periods of growth was selected[15].

Lue et al. developed a program for water resources systems under uncertainty using interval stochastic dynamic programming. A hypothetical water resource system was considered for implementing the model and the two models of stochastic dynamic programming and interval-number optimization were used in combination to manage water resource. The system under their study had three urban, agricultural and industrial consumers with a programming for a period of 15 years which consisted of three 5-year periods. Also, they analyzed those factors that affected the yield of the system. The information obtained from this analysis could be an important decision support for resource managements[16].

Huanga et al. developed a model which was created by two-stage stochastic model with inexact quadratic program (IQP)*. In this study, a hydrological method was used for the prediction of irrigation water. The purpose of this study was to maximize system profits for water resource management[17].

In this study, it was tried to present an optimal program for the allocation of the water behind Voshmgir dam among agriculture, industry and environment consumptions. In this way, the optimal allocation of irrigation water among different products has been studied.

2 Materials and Methods

Voshmgir dam was constructed in Golestan province and 45 km northeast of Aqqala city and about 5 km east of Anbar Alum on Gorganrood main stream basin. The initial design, capacity adjustment and also water passage power of dam network irrigation canals were for 60% grain and 40% cotton which means that out of the total 21 thousands hectares of the network, 12 thousand and 600 hectares of the region should be wheat acreage and 8 thousand and 400 hectares cotton acreage.

Dual use of water reservoirs and wetlands available in the network for aquaculture simultaneous use of water for agriculture has caused the production of more than 1,300 tons of fish in this dam, annually. Currently, maximum irrigation capacity of Voshmgir dam is about 12,400 hectares that due to non-compliance of cropping pattern (60% grain and 40% cotton) by farmers caused incomplete irrigate of crops, creation of conflict, disruption of crop irrigation, and crop failures. Conversion of initial 50-hectare plots to 5-hectare parts, conversion of economical agriculture to subsistence agriculture, increasing the acreage of rice which is the most water using crop in the province, lack of progress and change in irrigation methods in the lands and other social and economic issues have increased Voshmgir operation problems and made the polar of the population resident in the region concerned. Acreages of cotton and corn have decreased from 8400 to 5400 hectares and from 12,600 to 7,000 hectares, respectively [18].

Mathematical models are used as a tool for achieving the goals of managers and planners of reservoir systems. Studies conducted with optimization have shown that no general method can be mentioned to solve all the problems of water resources.

Linear programming has long been considered as one of the best and the most important management and programming tools in agriculture. Use this tool dates back to the 50's and researches of people like Heady (1954) and King (1953)[19].

* . Inexact Quadratic Program

The general form of a linear programming model to maximize the objective function is fitted as follows:

$$
\begin{aligned}
&Max \quad z = cx \\
&s.t. \\
&\qquad Ax \leq b, \\
&\qquad x \geq 0.
\end{aligned}
$$

Where z, x, c, A and b are objective function value, decision variables, the contribution of each variable in the objective function, the matrix of technical coefficients, and right side values of the constraints, respectively. Resulting set of answer consists of optimal values of desired activities[20].

The goal of most optimization models in reservoir systems is to maximize the profits of all consumers from these systems by optimal allocation of constraining factor of water to consumers. Before describing the optimization model of water supply network under certainty, the basic assumptions of the model are as follows:

1. There are no temporal changes in soil physical and chemical properties.
2. Waste water per km along the main canals is the same.
3. Water is the most constraining factor of all consumers.
4. The objective function and all constraints are linear.

The problem of optimal allocation of water in Voshmgir reservoir network can be written:

$$
f: MAX\ Z = [(\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{c=1}^{C} A_{krct} Y_{krct} P_{krct} - \sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{c=1}^{C} A_{krct} CG - \sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{c=1}^{C} WI_{krct} CI_t)
$$
$$
+ (WA_t NA_t - WA_t CA_t) + (WEN_t NEN_t - WEN_t CEN_t)] \qquad \forall t
$$

In this model, the objective function is maximizing the profits gained from agricultural products, aquaculture, and environment from optimal allocation of Voshmgir dam water in a three-year time horizon.

f is system net profit of crops, aquaculture and environment from Voshmgir dam water allocation, k is the number of Voshmgir dam main canals for the irrigation of the agricultural regions around the dam, r is agricultural regions irrigated by each of the main canals, t is time horizon, c is the main crops of each region including wheat, barley, alfalfa, canola, cotton, rice, cotton-melon, and maize. A_{krct} is the acreage of c crop from k canal for r region corresponding to the product of the canal in t time period (decision variable), Y_{krct} is the yield of c crop in r region from k canal in time horizon of t, P_{krct} is the average price of c crop, CG is the costs of cultivating c crop other than water cost, CI_t is the cost of each cubic meter of water used for the production of c crop in t period, NA_t is the profit rate of water consumption per cubic meter allocated to the aquaculture sector in t period, CA_t is the cost of water per cubic meter in the aquaculture sector in t period, NEN_t is the profit rate of water consumption per cubic meter allocated to the environment sector in t period, WI_{krct} is the rare of the water allocated to c crop from k canal in r region for t year (decision variable), WA_t is the amount of water allocated to the aquaculture sector in t period (decision variable), and WEN_t is the amount of water allocated to the environment sector in t period (decision variable).

Constraint of the available land:

$$\sum_{c=1}^{C} A_{krct} \le TA_{krt} \qquad \forall k,r,t$$

TA_{krt} is the total crops acreages in r region from k canal in t period of available water constraint in each main canal:
σ_{krt} is the amount of waste water for each region of r from k canal in the time horizon of t, and Ca_{kt} is the capacity of the canal in t period.
Constraint of the available water:

$$\sum_{r=1}^{R}\sum_{c=1}^{C} W_{krct}(1+\sigma_{krt}) \le Ca_{kt} \qquad \forall k,t$$

$$q_c = \frac{NW_c}{rn}$$

q_c is the amount of gross water needed for c crop, NW_c is the amount of net water required for c crop, and rn is the irrigation efficiency.
Reservoir capacity constraint

$$S_t + \sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{c=1}^{C} W_{krct} + W_{At} + W_{ENt} + E_t \le C_{reservoir} \qquad \forall t$$

S_t is the reservoir capacity in t year (decision variable), E_t is the rate of evaporation from the reservoir dam surface, and $C_{reservoir}$ is reservoir dam capacity
Inflow water constraint:

$$\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{c=1}^{C} WI_{krct} + WA_t + WEN_t + E_t - S_t \le W_t \quad \forall t$$

Constraints related to alfalfa which is a perennial crop.

$$A_{kr(alfafa)t+1} = A_{kr(alfafa)t} \qquad \forall k,r,t$$

$A_{kr(alfafa)t+1}$ is alfalfa acreage in $t+1$ year, and $A_{kr(alfafa)t}$ is alfalfa acreage in t year.
Restrictions on the maximum and minimum water demand of products

$$D_{\min} WI_{krct} \le WI_{krct} \le D_{\max} WI_{krct} \qquad \forall k,r,c,t$$

$D_{\min} WI_{krct}$ is the minimum water needed for c crop in r region from k canal in t period, and $D_{\max} WI_{krct}$ is the minimum water needed for c crop in r region from k canal in t period.
Restrictions on the maximum and minimum water demand for warm-water fish:

$$D_{\min} WA_t \le WA_t \le D_{\max} WA_t \qquad \forall t$$

$D_{\min} WA_t$ is the minimum water required for aquaculture in the period of t and $D_{\max} WA_t$ is the maximum water requirements for aquaculture in the period of t.
Constraint on the maximum and minimum water demand for environmental section:

$$D_{\min} WEN_t \le WEN_t \le D_{\max} WEN_t \qquad \forall t$$

$D_{\min} WEN_t$ is the minimum water required for the environmental sector in t period,

and $D_{\max} WEN_t$ is the maximum water needed for the environment sector in t period.
Constraint on Non-negativity of the decision variables in the model

$A_{krct},\ WI_{krct}, WA_{At}, WEN_{ENt}, S_t \geq 0$

3 Results and Discussion

Figure 1 shows the Voshmgir dam irrigation network. As you can see, there are two main canals on both sides of Voshmgir dam. The length of the right main canal of this network is about 17.76 km and the length of the left main canal is about 21.338 km. In this study, $k = 1$ is considered for the right main canal and $k = 2$ is considered for left main canal. Lands under irrigation network are considered in three regions. Right bank regions and sample farm are covered by the network in the right part of the network and the left bank regions are covered by the network on the left. Thus, there is one region in the left side of the network and there are two regions on the right. The major crops cultivated in the agricultural lands of the network include wheat, barley, canola, cotton, alfalfa, sunflower, rice, cotton-melon, and maize. Table 1 shows the main products of each region separately. It is noteworthy that the same main crops are cultivated in both right and left banks.

Fig. 1 Voshmgir Dam Irrigation network
Source: Water Operation and Distribution Company of Golestan Province

Information of the crops acreages in the base year is presented separately in Table 3. Based on this table, in 2013, the total crops acreage was more than 21 thousand hectares. Grains with 67 percent and cotton with 10 percent were the largest crops acreages in all areas under study.

Table 1 The crops acreages around Voshmgir dam in 2013 (hectares per year)

crop	Region		
	Right Bank	Sample Farm	Left Bank
Wheat	4807	3243	3840
Barely	427	288	340
Canola	107	72	15
Cotton	2441	674	774
Alfalfa	0	100	0
Sunflower	1794.3	130	386
Rice	0	40	1300
Cotton-Melon	0	30	0
Maize	0	730	0

Source: research findings

Gross income is the information involved in obtaining the economic value of agricultural water. In Table 2, the amount of gross income and net income and other information is given for the calculation of these two factors.

Table 2 Net income for crops in the regions around Voshmgir dam in 2013 (costs in Riyals)

Crop	Yield (Kg Per ha.)	Per Kg Cost	Per C.M. Water Cost	Other Costs	Gross Income	Net Income
Wheat	2730	11550	666	16853640	31531500	12769860
Barely	2380	8580	605	16297000	20420400	2978806.4
Canola	2032	20900	1365	20666433	42468800	15388853.5
Cotton	1410	24200	821	27789977	34122000	9900131.1
Alfalfa	7000	5000	700	1830000	35000000	8451351.4
Sunflower	1580	20350	220	19243000	32153000	1094189.9
Rice	4417	30000	512	43837000	132510000	82570513.5
Cotton-Melon	23480	5500	910	95000000	129140000	27007567.6
Maize	36585	4233	550	16139025	154864305	134102307

Source: research findings

The profits obtained from aquaculture are shown in Table 3.

Table 3 Net income of warm-water cultured fish in the regions around Voshmgir dam in 2013 (costs in Riyal)

Type of source	Regulated Water (Dam-Wetland)	
Type of fish culturing	Single-purpose warm water (pools and farms)	Dual-purpose warm water (Wetland)
average Yield per hectare	2500	2500
average price per kg	24000	24000
.water price per c. m	127.2	72.25
Net income (Riyal / ha)	54900000	55000000
Net income (Riyal / m3)	2196	2200

Source: research findings

The environmental profits were measured using data from the economic valuation of water environmental profits in the context of the amounts consumers' and environmental enthusiasts' willingness to pay through the survey method and environmental valuation and the environmental profits of Voshmgir dam were estimated 20 Riyals per cubic meter.

Table 4 shows the net flow allocated to agriculture sector and its corresponding acreage which is related to c crop in r region from k canal of Voshmgir Dam for t year.

In this table, four different irrigation water efficiencies (37, 45 and 51 percent) are shown taking into account the uncertainty. It is considered that the maximum net flow allocation is in the efficiency of 35% for rice crop on the left bank and left region of the dam in the third year planning horizon ($WI_{krct} = 23.2$ million cubic meters) and in the efficiencies of 45 and 51 percent for rice crop on the left bank and left region of the dam in the third year planning horizon ($WI_{krct} = 16.9$ and 19.1 M.C.M., respectively). The main reason for the allocation of most water to rice production may be its higher gross profit per cubic meter in the objective function. Maximum acreage in the efficiency of 37% is for the cultivation of wheat on the right bank and right region of the dam in the second year of planning horizon ($A_{krct} = 6729.8$ ha) and in the efficiencies of 45 and 51 percent it is for wheat crop on the right bank and right region of the dam in the second year of planning horizon (6729.8 hectares).

Table 4 shows the net flow and the allocated acreage with different efficiencies.

$krct$ Index	Allocated flow (M.C.M)			Acreage (ha)		
	Irrigation efficiency			Irrigation efficiency		
	37%	45%	51%	37%	45%	51%
Right- Right bank- wheat -2014	17.9	14.7	12.99	6249.1	6249.1	6249.1
Right- Right bank- Barely-2014	1.05	0.26	0.23	555.1	170.8	170.8
Right- Right bank- Canola -2014	0.66	0.54	0.48	139.1	139.1	139.1
Right- Right bank- Cotton-2014	10.03	8.25	7.28	976.4	976.4	976.4
Right- Right bank- Sunflower-2014	14.66	15.01	13.25	1638.9	2040.9	2040.9
Right- Right bank- wheat-2015	19.28	15.85	13.99	6729.8	6729.8	6729.8
Right- Right bank- Barely-2015	1.13	0.33	0.29	579.8	213.5	213.5
Right- Right bank- Canola -2015	0.04	0.58	0.51	7.5	149.8	149.8
Right- Right bank- Cotton-2015	12.54	10.31	9.09	1220.5	1220.5	1220.5
Right- Right bank- Sunflower-2015	9.13	9.29	8.2	1020.7	1262.7	1262.8
Right- Right bank- wheat- 2016	18.96	15.59	13.76	6618.4	6618.4	6618.4
Right- Right bank- Barely-2016	0.48	0.40	0.35	256.2	256.2	256.2
Right- Right bank- Canola -2016	0.76	0.62	0.55	160.5	160.5	160.5
Right- Right bank-Cotton-2016	15.04	12.37	10.91	1464.6	1464.6	1464.6
Right- Right bank- Sunflower-2016	9.63	7.92	6.99	1076.6	1076.6	1076.6
Right - Sample farm- wheat- 2014	17.90	14.72	12.99	4215.9	4215.9	4215.9
Right- Sample farm- Barely-2014	0.41	0.18	0.16	214.9	115.2	115.2
Right- Sample farm- Canola -2014	0.44	0.36	0.32	93.6	93.6	93.6
Right- Sample farm- Cotton-2014	2.77	2.28	2.00	269.6	269.6	269.6
Right- Sample farm-alfalfa- 2014	0.92	0.59	0.52	78	78	78
Right -Sample farm- Sunflower-2014	0.47	1.24	1.1	52	169	169
Right- Sample farm- Rice- 2014	0.62	0.51	0.45	52	52	52
Right- Sample farm-Vegetable- 2014	0.33	0.27	0.24	39	39	39
Right- Sample farm- Maize- 2014	2.29	1.88	1.66	292	292	292
Right- Sample farm- wheat- 2015	11.8	9.74	8.6	4119.2	4136.5	4136.5
Right - Sample farm- Barely- 2015	0.27	0.22	0.20	144	144	144
Right- Sample farm- Canola - 2015	0.48	0.39	0.35	100.8	100.8	100.8
Right- Sample farm- Cotton - 2015	3.46	2.85	2.51	337	337	337
Right- Sample farm- alfalfa - 2015	0.92	0.59	0.52	78	60.7	60.7
Right- Sample farm- Sunflower - 2015	0.58	0.48	0.42	65	65	65
Right- Sample farm- Rice- 2015	0.67	0.55	0.48	56	56	56
Right- Sample farm-Vegetable- 2015	0.35	0.29	0.26	42	42	42
Right- Sample farm- Maize- 2015	25.86	23.52	20.76	365	365	365
Right- Sample farm- wheat- 2016	11.25	9.28	8.19	3925.8	3940.1	3940.1
Right - Sample farm- Barely- 2016	0.33	0.27	0.24	172.8	172.8	172.8

krct Index	Allocated flow (M.C.M)			Acreage (ha)		
	Irrigation efficiency			Irrigation efficiency		
	37%	45%	51%	37%	45%	51%
Right- Sample farm- Canola - 2016	0.51	0.42	0.37	108	108	108
Right- Sample farm- Cotton -2016	4.15	3.41	3.01	404.4	404.4	404.4
Right- Sample farm- alfalfa - 2016	0.92	0.59	0.52	78	78	78
Right- Sample farm- Sunflower - 2016	0.70	0.57	0.51	78	78	78
Right- Sample farm- Rice- 2016	0.72	0.59	0.52	60	60	60
Right- Sample farm-Vegetable- 2016	0.35	0.31	0.27	42	45	45
Right- Sample farm- Maize- 2016	3.43	2.82	2.49	438	438	438
Left- Left bank - wheat - 2014	12.45	10.24	9.03	4345.5	4345.5	4345.5
Left - Left bank - Barely -2014	0.26	0.21	0.19	136	136	136
Left - Left bank - Canola - 2014	0.09	0.08	0.07	19.5	19.5	19.5
Left - Left bank - Cotton - 2014	3.18	2.61	2.31	309.6	309.6	309.6
Left- Left bank - Sunflower - 2014	1.39	1.14	1.00	154.4	154.4	154.4
Left - Left bank - Rice -2014	20.14	16.56	14.61	1690	1690	1690
Left- Left bank - wheat - 2015	11.64	9.57	8.45	4064	4064	4064
Left - Left bank - Barely -2015	0.32	0.26	0.23	170	170	170
Left - Left bank - Canola - 2015	0.1	0.08	0.07	21	21	21
Left - Left bank - Cotton - 2015	3.97	3.27	2.88	387	387	387
Left- Left bank - Sunflower - 2015	1.73	1.42	1.25	193	193	193
Left - Left bank – Rice- -2015	21.69	17.87	15.74	1820	1820	1820
Left- Left bank – wheat- - 2016	10.84	8.91	7.86	3782.5	3782.5	3782.5
Left - Left bank - Barely- 2016	0.39	0.32	0.28	204	204	204
Left - Left bank - Canola - 2016	0.11	0.09	0.08	22.5	22.5	22.5
Left - Left bank - Cotton - 2016	4.77	4.77	3.92	3.46	464.4	464.4
Left- Left bank - Sunflower - 2016	2.07	1.70	1.50	231.6	231.6	231.6
Left - Left bank - Rice -2016	23.24	19.11	16.86	1950	1950	1950

Source: research findings

Considering the allocation of water to the main canals at both sides of Voshmgir dam according to different regions covered by the dam is one of the important issues in this study. Given that the current allocation of water to the main canals of the dam does not follow a specific rule and it is severely fluctuating based on annual cropping pattern of each side of the dam, determining the amount of allocated flow to each of the two branches of the main canals of Voshmgir dam seems to be necessary.

Table 5. Shows the total amount of allocated flow to the main canal (left or right) in the three efficiencies of 37, 45, and 51 percents. It is seen that the highest water allocation in all three efficiencies are related to the main right canal in the first year of planning horizon (2014) with 44.30, 38.78 and 34/22 M.C.M., in a second year of planning horizon (2015) with 42.11, 36.36, and 32.56 M.C.M., and in the third year of planning horizon (2015) with 44.88, 36.90 and 32.56 M.C.M. As it is observed, with increasing irrigation efficiency. The rate of water release from dam to each canal is reduced.

Table 5 The total allocated flow to the main canals on both sides of the dam in different efficiencies.

Explanation	Total allocated flow (MCM)		
	Irrigation efficiency		
	37%	45%	51%
Right side main canal of the first year	64.62	56.03	49.44
Right side main canal of the second year	63.51	53.82	47.49
Right side main canal of the third year	67.23	55.17	48.68
Left side main canal of the first year	37.50	30.84	27.21
Left side main canal of the second year	39.46	32.44	28.63
Left side main canal of the third year	41.41	34.05	30.05

Source: research findings

The amount of water allocated to each region under the study is one of the major issues in rationing water for Voshmgir dam irrigation system that has undergone severe changes based on annual cropping pattern and the acreage of different agricultural lands. Figure 2, 3 and 4 show the amount of allocated flow to the three desired areas for each side of the dam in the three-year planning horizon and in different efficiencies. It can be considered that the maximum flow allocation is mainly related to the right region on the right side of the dam. The answer seems logical because most of the lands covered by water network of Voshmgir dam (right) are located in this region.

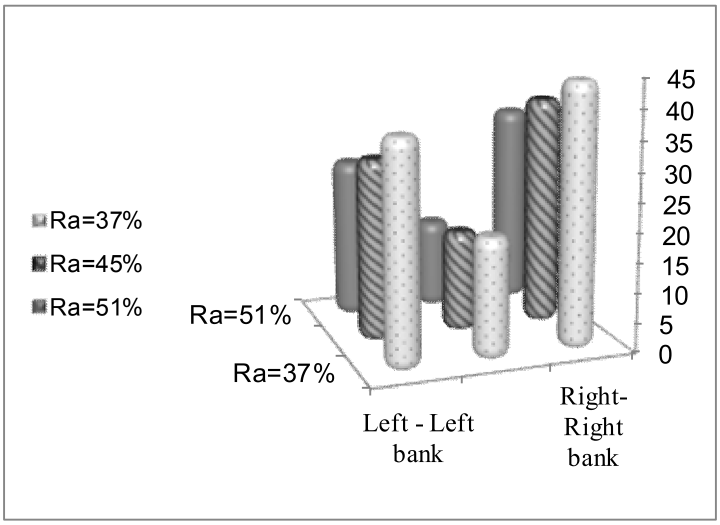

Fig. 2 The allocated flow of different regions in the first year of planning horizon (2014)

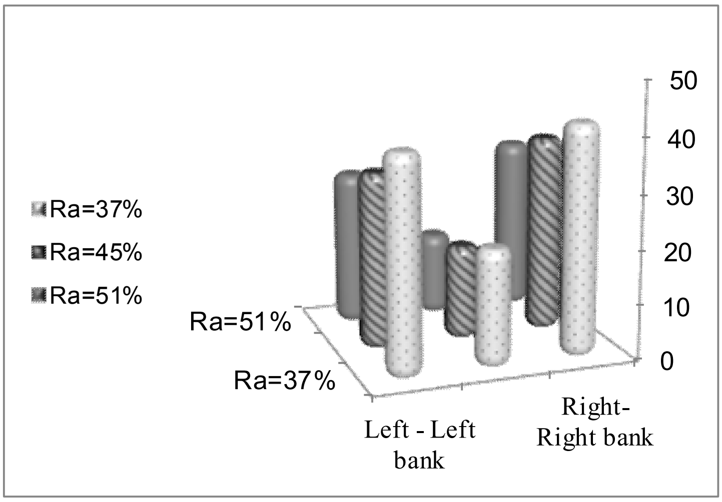

Fig. 3 The allocated flow of different regions in the second year of planning horizon (2015)

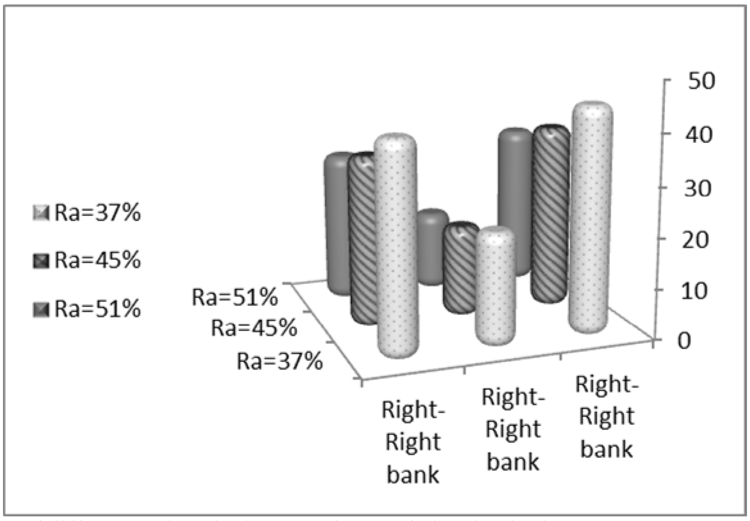

Fig. 4 The allocated flow of different regions in the second year of planning horizon (2015)

Table 6 shows the amount of water allocated to aquaculture activities in the three-year planning horizon. The allocated water to this section does not undergo any changes under different efficiencies. Given that this is a profitable activity, maximum water allocation intended for this section is provided. As you can see, the maximum water allocation to this sector is in the third year of planning horizon (20.47 M.C.M.).

Table 6 Net flow allocation to aquaculture section under different efficiencies

Planning time horizon	Total allocated flow (M.C.M)		
	Irrigation efficiency		
	37%	45%	51%
2014	19.17	19.17	19.17
2015	18.82	18.82	18.82
2016	20.47	20.47	20.47

Source: research findings

Table 7 shows the amount of Voshmgir dam water allocated to the environment section under different efficiencies. As it can be seen, minimum allocation of dam water in all three years of planning horizon was to the environmental section under the efficiency of 37%.

Table 7 shows the net flow allocated to the environmental section under different efficiencies

Planning time horizon	Total allocated flow (M.C.M)		
	Irrigation efficiency		
	37%	45%	51%
2014	9.27	11.9	11.9
2015	9.89	11.31	11.31
2016	9.67	11.51	11.51

Source: research findings

Table 8 shows the amount of surplus water remained in the dam in 2014 and 2015 under different efficiencies. As you can see, most of the surplus water is in the year 2015 and at 51% efficiency (96.29 M.C.M). With the increase in irrigation efficiency due to the smaller amount of water allocated to the agriculture section, aquaculture, and environmental sectors profit more from water allocation and the surplus water that remains in the dam increases for the next year.

Table 8 shows the surplus water of the dam in the three-year planning horizon under different efficiencies.

Planning time horizon	Total allocated flow (M.C.M) Irrigation efficiency 37%	45%	51%
2014	15.70	28.33	17.43
2015	18.46	0.87	29.96

Source: research findings

Figure 5 shows the net profit of the system in different efficiencies. As it is observed, system profit increases with increasing irrigation efficiency. For example, net profit of the system in the three-year planning horizon will reach to 1,680 billion Riyals at 51 percent efficiency from 1620 billion Riyals in the efficiency of 37 percent. In addition, with increasing irrigation efficiency and increasing the amount of net profit per cubic meter, maximum and minimum water demand for irrigation is reduced. Of course, the reduction in the minimum amount of irrigation water demand for the products that have lower gross profit also may be influential. Regarding that the irrigation efficiency does not affect the aquaculture sector, the system net profit in this section is fixed in various efficiencies, but efficiency in the environmental sector has a direct effect on this part because to maintain the environmental sector, it is necessary to keep some water in the dam each year for the next year to avoid its destruction. Then it can influence this sector by surplus water. By increasing efficiency, the amount of water allocated to agriculture is reduced; therefore, the surplus dam water for the next year is increased and enhances the environmental sector profit from efficiency of 35% to 51%.

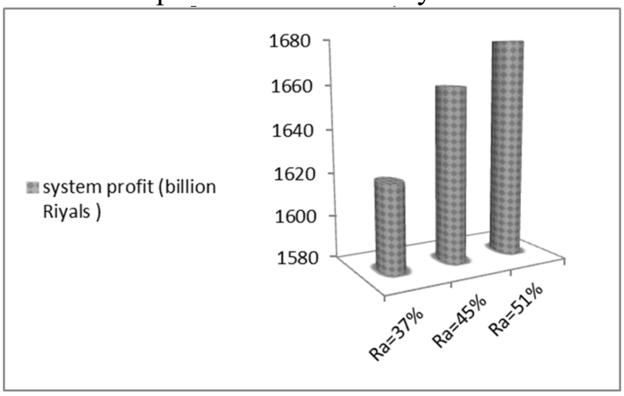

Fig. 5 The total system profit in three-year planning horizon

Table 9 Net profit from different sectors during the three-year planning horizon under different efficiencies

Time horizon	Agriculture 37%	Agriculture 45%	Agriculture 51%	Aquaculture 37%	Aquaculture 45%	Aquaculture 51%	Environmental 37%	Environmental 45%	Environmental 51%
2014	792.53	809.22	1250.62	42.1	42.1	42.1	0.19	0.24	0.24
2015	882.99	901.03	907.93	45.46	45.46	45.46	0.2	0.23	0.23
2016	988.92	1003.78	1011.67	54.40	54.40	54.40	0.19	0.23	0.23

Net profit per unit (Million Riyals); Irrigation efficiency

Source: Research findings

4 Conclusions and Recommendations

In this study the optimal allocation of water among agricultural, aquaculture and environmental sectors were studied. Furthermore, in agriculture sector, water allocation to the farmlands surrounding Voshmgir dam among the three regions and seven major crops in the lands covered by the two sides of the dam was studied. For water allocation, a three-year planning horizon (2014-2016) was considered. The data of the time series between the years of 2001 to 2013 were collected and analyzed to organize the information needed for the model solution. The volume of water entering the irrigation system for planning horizon was predicted using Monte Carlo simulation. Waste water in the main canals of network was calculated by deducting a percentage of the amount of water flow from the dam for each canal of the dam. To forecast the gross profit of each crop in each region for the planning horizon, the ARIMA model was used. The price of irrigation water was also calculated from the average price of the last 5 years and was considered fixed for three years planning horizon.

The results showed that the maximum net flow allocation is in 35% efficiency of rice in the left bank and left region of the dam in the third year of planning horizon (23.2 M.C.M.) and in the efficiencies of 45 and 51 percent it is related to rice in the left bank and left region of the dam in the third year of planning horizon (16.9 and 19.1 M.C.M., respectively). The maximum acreage is in the efficiency of 37% for wheat cultivation on the right bank and right region of the dam and in the second year of planning horizon (6729.8 ha) and in the efficiencies of 45 and 51 percent it is related to wheat on the right bank and right region of the dam and in the second year of planning horizon (6729.8 ha). It is observed that with efficiency increase of 37 percent to 51 percent, the amount of allocated flow is decreased while the acreage remains constant. The maximum water allocation in all three efficiencies is related to the right main canal in the first year of planning horizon (2014) with 44.30, 38.78 and 34.22 M.C.M, respectively, in the second year of planning horizon (2015) with 42.11, 36.36 and 32.08 M.C.M. and in the third year of planning horizon (2015) with 44.88, 36.90 and 32/56 M.C.M. The amount of water allocated to aquaculture sector does not change under different efficiencies and irrigation efficiency in the agricultural sector does not affect this variable. Water allocation to environmental sector in all three years of planning horizon under the efficiency of 37% is the minimum amount.

1. Increase in irrigation efficiency will increase the gross profit of the farmers from water transferring. Therefore, policies that increase the efficiency of irrigation water, such as investment in water saving technologies are recommended.
2. Given the current condition of Voshmgir dam, its acute water shortage, and reduced water consumption with increasing uncertainty, use of water and agricultural land allocation pattern with high risk is recommended. To compensate the farmers' gross profit reduction due to the use of this pattern, insurance policies are recommended as well.
3. The right canal has the maximum water allocation from Voshmgir dam. Due to the old and worn constructions, rehabilitation of irrigation network (main canals) is recommended to reduce water waste.

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