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SUMMARY – Considering water resources limitations, increasing water demands and occurrence of frequent droughts in our country, reducing water consumption and using available water with optimal management are to be dealt with. The main objective of this study is to compare the optimization and equitable water reduction approaches in agriculture water demand management during drought in such way that minimizes the consequent damages. To explore these methodologies, the 1999 drought of the Zayandeh Rud irrigation system has been evaluated. Furthermore, the required models have been developed. In the case of the Optimization method, the crops growth stages and their sensitivity to water stress were embedded in the calculations. The results show that the Optimization method associates 36% more income for the agriculture sector applying the same amount of water. This difference emphasizes the importance of water allocation with respect to growth stages rather than cutting the same amount of water to combat water scarcity. However managing the system by the Optimization method is more complex and needs more infrastructures to make it applicable.

Key words: Demand management, simulation, optimization, managing of water supplies during drought.

Introduction

Iran is frequently hit by droughts. One of the severest recent droughts occurred during 1999 in Zayandeh Rud basin, which is located in the central part of the country. The optimal water allocation is an efficient measure to mitigate the consequent losses in such a condition (Ghahreman and Sepaskha, 2002; Kumar *et al.*, 2006). For instance, Mohan and Arumugam (1997) and Shangguan *et al.* (2002) reported 50% reduction in water demands during water scarcity condition, by optimization techniques.

But in operational works, it is more routine and convenient for water managers to apply equitable reduction method, which is named "Vonesh" in Iran. This kind of water management is also applied in other country during droughts, like Mexico (Palmer *et al.*, 2002; Vigerstol, 2003).

Comparison of optimization and equitable reduction approaches for water allocation in water scarcity conditions is the objective of this paper. The Zayandeh Rud irrigation system and the 1999 droughts are selected to illustrate the methodology. The system includes 8 irrigation units namely, Nekouabad LB, Nekouabad LR, Mahyar, Borkhar, Abshar LB, Abshar LR, Rudasht and Small-scale System with total area of about 180,000 ha. Wheat, barley, sugar beet, alfalfa and rice are also the dominant crops within the basin.

Data and Methods

Optimization method (OPM)

This method is applied by developing 3 sub-models that gains to some extent from the methodology suggested by Shangguan *et al*. (2002). The structures of sub-models are presented in Fig. 1.

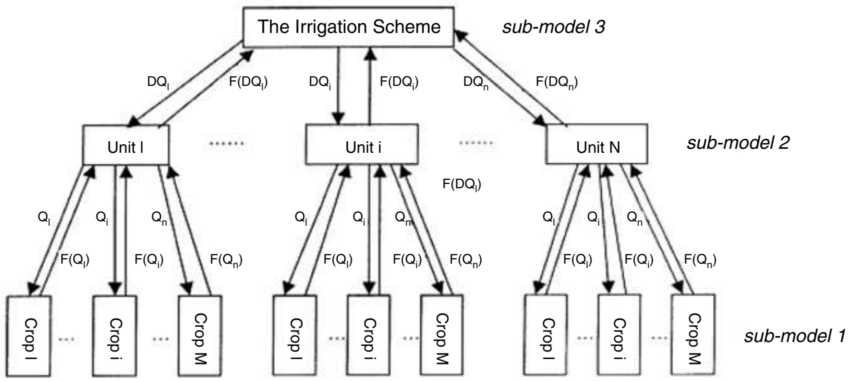

Fig. 1. The frame work of the optimization model for water allocation.

The sub-model 1: Irrigation scheduling optimization for individual crops

The sub-model 1 calculates optimum water during growing season base on a 10 days irrigation period for each crop. Objective function is to maximize crop production per hectare:

$$MAX : \frac{Y_{ac}}{Y_{\max c}} = 1 - \sum_{g=1}^{n} Ky_g \left(1 - \frac{ETa_{c,g}}{ET\max_{c,g}}\right) \tag{1}$$

where $ETa_{c,g}$ is crop actual evapotranspiration in stage g (mm/10days) of growing period; $ET\max_{c,g}$ is the crop maximum evapotranspiration in stage g (mm/10days); Ky_g is the crop sensitivity coefficient in stage g (Doorenbos and Pruitt, 1984), n is the total number of growth stages; Y_{ac} is the actual yield per unit area and $Y\max_c$ is the maximum yield per unit area (kg/ha) (Allen *et al*., 1998).

The sub-mode 2: Water allocation and planted acreage optimization across crops

The objective function for this sub-model is to maximize the summed benefit of all crops within an irrigation unit:

$$MAX\left\{\sum_{k=1}^{K} F_K(Q_K) A_K Y_{\max k} P_K\right\} \tag{2}$$

where K is the total number of crops; $F_K(Q_k)$ is the functional relation between maximum relative yield and allocated irrigation water for crop k; A_k is the acreage for crop k (ha); Y_{MAXK} s the maximum yield for crop k (kg/ha) and P_k is the marketing price (US$/kg) for crop k. In order to calculate $F_K(Q_k)$ for crop k, the first sub-model needs to be run with various values of Q_k. Therefore, a set of optimized benefit values $F(Q_k)$ can be computed.

The sub-model 3: Model for water allocation optimization among the irrigation units

The last sub-model distributes optimally the total release of the reservoir between the irrigation units. Objective function is to maximize the summed benefit of all the units, as follow:

$$MAX\left\{\sum_{n=1}^{N} F_n(Q_n)\right\} \tag{3}$$

where N is the total number of units; $F_n(Q_n)$ is the functional relation between maximum benefit and allocated water for each unit.

Equitable reductions method (ERM)

To calculate amount of irrigation water according to this method, ration (REW) of the maximum demand (MD) of the irrigation units to maximum available water from the dam (MAW) needs to be calculated (REW= MD/MAW). Then, amount of (1-REW)*100% reduces from the MD of each unit. Similar amount of water is consequently reduces from the crops maximum water requirement of each unit. In this process no changes is applied in the cropped area. Finally, crop yield is estimated by substituting REW by *ETa/ETmax* in equation 1.

Results and discussion

Comparison of the irrigation units' performances, using the OPM and ERM methods

The results of the two approaches that needed huge calculations are shown in Table 1. The table shows that more than 33% increase in incomes can be expected, using the OPM. Notably, the difference between the total cropped areas is less that 4%. In other word, it emphasizes on importance of water allocation to manage the network during droughts rather than changing cropped area that has its own social obstacles. The allocated water to the different crops within the units is shown in Fig. 2. It is also worthy to mention that applying the OPM causes 34%, 23%, 15% and 45% increase in wheat, barely, alfalfa and potato productions (Fig. 3).

Table 1. Estimated income and using OPM and ERM methods

Irrigation Units	Cropped Area (ha)		Income (US$)x10^{8}	
	ERM	OPM	ERM	OPM
Nekouabad LB	36,608	38,596	0.856	1.35
Nekouabad LR	14,081	14,779	0.347	0.518
Mahyar	27,796	28,385	0.993	1.53
Borkhar	25,032	26,036	0.733	1.2
Abshar LB	31,122	32,372	0.912	1.52
Abshar LR	17,985	18,819	0.506	0.815
Rudasht	57,806	59,468	2.04	3.13
Small-scale Systems	49,727	51,223	1.43	2.17
Area Total	260,157	269,678	7.82	12.2

Conclusion

This research work was an attempt to compare the optimization and the traditional equitable reductions methods to reduce drought losses in Zayandeh Rud irrigation system during the 1999 drought. The following conclusions can be drawn from this study:

(i) The three layers modeling setup was relevantly able to perform required calculations for water allocation with the irrigation units and irrigation scheduling.

(ii) The OPM approach could increase the network's income up to 36% and can be considered as a recommended measure to mitigate risk of droughts.

(iii) The results showed that changing the cropped area doesn't have significant impact of the networks' income during droughts. But, irrigation scheduling and deficit irrigation can be considered as effective measures in water scarcity situation.

(iv) Responses of wheat and sugar beet were more significant to water allocation based on the OPM.

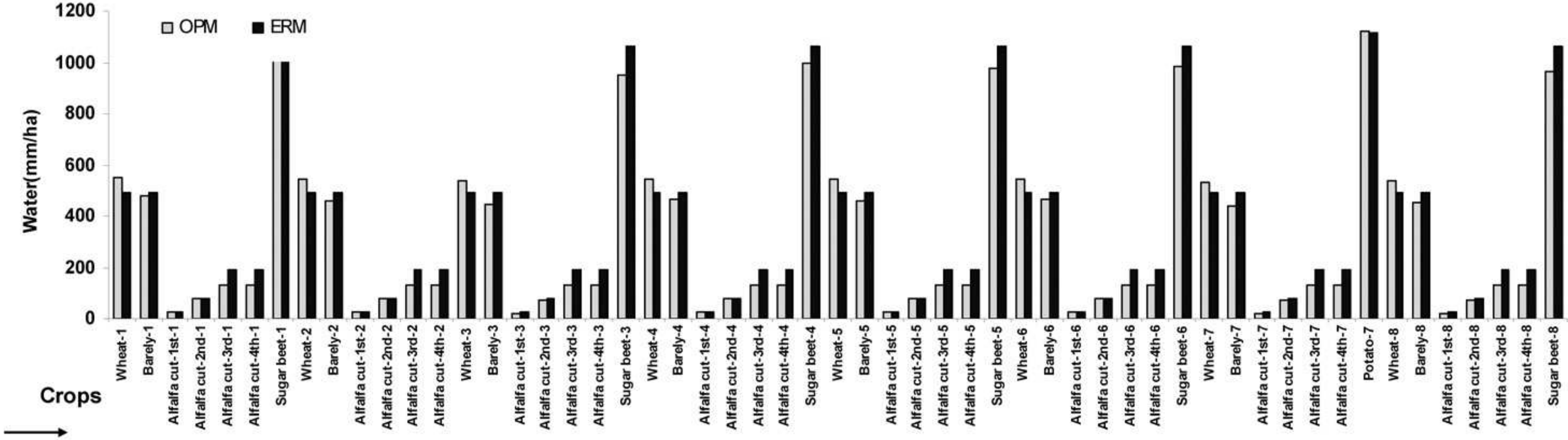

Fig. 2. Water distribution among crops in the irrigation units (1) Nekouabad LB, 2) Nekouabad LR, 3) Mahyar, 4) Borkhar, 5) Abshar LB, 6) Abshar LR, 7) Rudasht, 8) Small-Scale systems).

(v) In spit of positive results of the OPM, it should be considered that the execution of the EWM method is much easier for the basin water organization. So, to have the OPM method more operational, attempts need to be devoted for training the basin's water mangers and extension activities for the farmers.

(vi) Annual streamflows and temperature forecasts improve the capability of the OPM that are under processed by the authors.

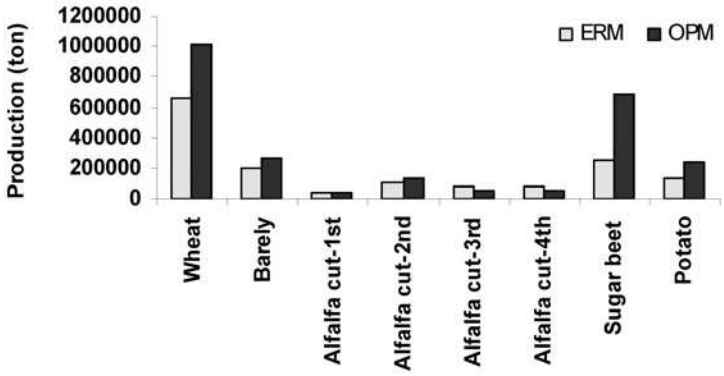

Fig. 3. The total production in the Zayandeh Rud irrigation system.

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