EFFECTS OF SURFACE IRRIGATION EFFICIENCY IMPROVEMENT ON WATER RESOURCES SYSTEM INDICES

EFFETS DE L'AMÉLIORATION DE L'EFFICACITÉ D'IRRIGATION DE SURFACE SUR LES INDICES DE SYSTÈME DES RESSOURCES

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ABSTRACT

Scarcity and uncertainty associated with water resources due to climate change is one of the biggest challenges facing agricultural water management. An effective measures can be to increase the efficiency of irrigation in agriculture. The purpose of this paper is to evaluate the effects of increasing surface irrigation efficiency on water resource system indices, including the reliability and vulnerability of water resources in the water resources system in order to combat water scarcity. For this purpose, one of the major basins in Iran was simulated in WEAP model as integrated. Dez basin located in the southwest of Iran is one of the agricultural poles in the region, which has a large population in the agricultural sector, and annually uses 4 billion m^3 of water from the Dez reservoir to the surface irrigation networks of this area. However, the low network efficiency causes millions of cubic meters of fresh water to be lost each year. The analyzed scenarios consisted of combining two modes of changing consumption in the short and long term with management scenarios including an increase of 5% and 15% efficiency of surface irrigation networks. The combination of these scenarios was simulated and implemented in WEAP model. The results indicated that in the short term, with increasing irrigation efficiency of 5%, the system reliability could be maintained. Increase of 15% improved irrigation efficiency by 1.9% and system vulnerability by 5% and 15% efficiency increase reduced by 1.6 and 2.96% respectively. Simulation results for the long term also indicated that the increase of 5% and 15% efficiency did not have an effect on the improvement of the reliability index. To improve this index, the system requires more increases in irrigation efficiency. The results also indicated that the rate of the vulnerability index in 5 and 15% efficiency increase, reduced by 1.61 and 4.46% respectively.

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Keywords: Irrigation efficiency, Weap, Reliability, Vulnerability, Iwrm, Water scarcity.

RÉSUMÉ

La rareté et l'incertitude associée aux ressources en eau dues au changement climatique est l'un des plus grands défis de gestion des eaux agricoles. Des mesures efficaces peuvent être prises pour accroître l'efficacité de l'irrigation dans l'agriculture. Le but de cette étude est d'évaluer les effets de l'accroissement de l'efficacité de l'irrigation de surface sur les indices de système de ressource de l'eau, y compris la fiabilité et la vulnérabilité des ressources en eau dans le système de ressources d'eau afin de lutter contre la pénurie d'eau. À cet effet, un des principaux bassins en Iran a été simulé dans un modèle WEAP comme étant intégré. Le bassin Dez situé dans le sud-ouest de l'Iran est un des pôles agricoles dans la région, avec une grande population dans le secteur agricole et utilisant chaque année 4 milliards de m3 d'eau provenant du réservoir de Dez pour les réseaux d'irrigation de surface de cette région. Toutefois, la faible efficacité du réseau provoque la perte de millions de mètres cubes d'eau douce chaque année. Les scénarios analysés consistaient en la combinaison des deux modes de l'évolution de la consommation à court et à long terme avec des scénarios de gestion comprenant une augmentation de 5 % et 15 % de l'efficacité des réseaux d'irrigation de surface. La combinaison de ces scénarios a été simulée et implémentée dans le modèle WEAP. Les résultats ont indiqué que dans le court terme, avec l'efficacité de l'irrigation accrue de 5 %, la fiabilité du système pourrait être maintenue. L'augmentation de 15 % améliorée efficacité de l'irrigation par la vulnérabilité de système et de 1,9 % en augmentation de 5 % et 15 % efficacité réduite respectivement de 1,6 et 2,96 %. Les résultats de la simulation à long terme ont également indiqué que l'augmentation de 5 % et 15 % d'efficacité n'avait pas d'effet sur l'amélioration de l'indice de fiabilité. Afin d'améliorer cet index, le système exige des augmentations plus dans l'efficacité de l'irrigation. Les résultats indiquent également que le taux de l'indice de vulnérabilité en 5 et 15 % augmentation de l'efficacité, réduite de 1,61 et 4,46 % respectivement.

Mots clés : Efficacité de l'irrigation, Weap, fiabilité, vulnérabilité, GIRE, pénurie d'eau.

1. Introduction

Water scarcity is a key issue affecting the entire global system, especially the water supply systems in the world (Liu et al., 2017; Hoekstra, 2016). Today, with the world's being exposed to climate change (Leroy Poff, 2016; Al-Kalbani et al., 2014; DeNicola et al., 2015) and the rising demand (Khan, 2017; Eliasson, 2015) and changing consumption patterns (Khan, 2017), it is predicted that water scarcity will expand (Wada et al., and 2013; Hong et al., 2016), and consequently supply and demand supply of water to protect human beings and the environment would become one of the greatest challenges of the 21st century (Leroy Poff, 2015). In such a situation, the planning and management of supplying demand to combat water scarcity has become much more complicated than before (Hong et al., 2016, Shamiraet al., 2015) due to the limited adaptive capacity of water resource systems (Al-Kalbaniet al., 2014). Although there are various managerial solutions to achieve the objectives of supplying water in a water supply system (Garothe et al., 2016), among them, integrated planning and management of water resources, due to considering all the components and factors that are effective on the modeling conditions of the integrated system (Garrote et al., 2016; Khan, 2017; Hong et al. 2016) has a higher potential for use in areas facing water scarcity (Garrote et al., 2016). Like many other countries in the world, Iran has recently faced a water scarcity crisis in most of its provinces. In this regard, one of the most effective measures can be to increase the efficiency of irrigation in agriculture. Surface-water irrigation networks are widely used in agriculture and food supply in Iran, and they play a key role in water resources of the country. However, most of the studies in Iran have shown that the efficiency of these irrigation networks is less than 33% (Navidi et al., 2017). So far, numerous studies have been conducted around the world to monitor, model, and make integrated decisions and evaluate the reliability and vulnerability indicators in catchment areas (Dessuet al., 2014; Gao et al., 2014; Al-Kalbani et al. 2014).the effects of increasing Surface irrigation efficiency in water resource management of Sistan provincein Iran was studied by Zamani et al (2015); The research analyzed the scenario of increasing surface irrigation efficiency and declared surface irrigation efficiency of 34% in Sistan area. The results of this research showed that if efficiency improvement is performed via using new irrigation methods, the amount of water resource increases and the needs unsupplied in other sectors are highly removed. Abdolshahnejad et al (2015) investigated the challenges of managing Hamidieh surface irrigation network in Iran. The results of simulation showed that water resource shortage in the studied area will be very serious during time. Therefore, the authors felt that some solutions such as changes in the method of water distribution and more control on water transfer might improve performance and reliability on the network water availability. Santikayasa (2016) presented a model for developing integrated planning in Sitarum River in Indonesia. They evaluated system reliability comparing irrigation water demand and delivered water. The results of this research showed that the reliability of system would decrease by 15% to 26%because of climate changes. The scientific community has recently made a strong recommendation to use indicators to assess and monitor progress towards sustainable development (Bolcárováand Kološta, 2015; Pireset al., 2017). Obviously, the use of water-resource system indicators to evaluate management and performance measurement will lead to a better allocation of current water resources (Kang & Lee, 2011; Pireset al., 2017). Reliability and vulnerability, as Hashimoto (1982) has defined, are criteria for measuring the dimensions and aspects of a water resource system's operation. Reliability and vulnerability are of the most comprehensive methods for analyzing the likelihood of success or failure of a system, the recovery rate (returning to the first place of recovery) from an unfavorable state (Asefaet al., 2014). Reliability and vulnerability indicators in a basin are highly influenced by the consumption pattern (Hong et al., 2016). On the other hand, scientific research has proven that the occurrence of climate change will reduce the reliability of water supply, increase the long-term depletion in the basins and reduce the feeding of aquifers (Shamiraet al., 2015).

Therefore, the purpose of this paper is to simulate and evaluate the effects of management options on the improvement of surface irrigation efficiency on water resource system indexes. This case has been investigated in one of Iran's largest surface irrigation networks known as Dez Surface Irrigation Networks. The analyzed indicators include reliability and vulnerability of agricultural water supply in two short and long horizons. The integrated simulation of the water resource system in the Dez Basin is based on the WEAP model which functions based on the water balance equation

2. Materials and methods

2.1 Study area

Dez basin is a subset of Great-Karun watershed; this is an important basin in Iran located in the geographical coordinates 32°, 35´ to 34°, 07´ North latitude and 48°, 20´ to 50°, 20´ east longitude, southwest of Iran. Dez river basin having the area of 23229 km^2 ends to Gharechaibasin in the north, Karun basin in the east and south and Karkhe basin in the west (Rostami et al., 2009). The location of this basin is shown in figure 1.

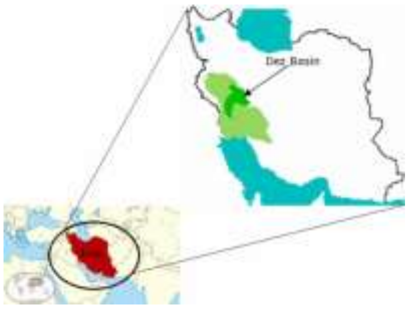

Figure1. Study area

Resources and uses system of Dez basin is very complex. This basin supplies the required water of agricultural, aquaculture and drinking sectors of the area. One of the great water consumptions in this area is in agriculture (KWPA, 2013). In order to supply the need of agricultural sector, more than 4 billion m^3 of water is annually allocated from Dez reservoir to surface irrigation network of 0.1 M ha area. Dez surface irrigation networks has a poor efficiency of less than 33% averagely (Navidi, 2016).

2.2 Crops water needs

Studies of monthly water need in Dez irrigation network are computed using standard method suggested in FAO-56. In these calculations, the values of evapotranspiration and effective monthly precipitation are obtained from meteorological Studies. After calculating net irrigation need by considering cultivation pattern and cultivated area of different crops, real demand of irrigation was estimated. Then total system irrigation efficiency was evaluated by comparing real demand of cultivation pattern and the allocated water level from Dez storage dam. This data is shown in table 1.

Table 1: Allocated water, real demands and total efficiency of Dez irrigation networks

Year	Allocated water (MCM)	Real demands (MCM)	Irrigation efficiency (%)	Surpluses water (MCM)
2011	2135.9	697.7	32.6	1438.2
2012	1613.1	605.1	37.5	1008
2013	1953.5	633.8	32.4	1319.7
2014	2254.8	715.4	31.7	1539.4
2015	2147.4	683.6	31.8	1463.8

With regard to table 1, it can be specified that the efficiency of Dez surface irrigation network is very low and at least 1 billion m^3 of water is annually wasted. In the system of Dez basin resources, while water transfer efficiency of Dez storage dam to agricultural lands is about 90%(Iran'sMinistry of Energy, 2014) but fatigue of tertiary and quaternary canals that cause great amount of water waste in agricultural lands, results in Dez surface irrigation and drainage networks that were built by the aim of increasing water efficiency in agricultural sector and preventing water loss, to be a pole of water loss in the area by their low efficiency.

2.3 Reliability index

In optimization methods, the influence of applying different policies on system performance of the intended water resources is evaluable with regard to goal functions and response set of points; while the results from applying different policies must be interpreted in simulation methods such that the possibility of selecting better policy is provided. One method which is proposed for evaluating the policies applied on a system of water resources is the use of operational indexes. Performance Indices (PI) are used for analyzing the efficiency and performance of different scenarios. These indices are divided into two general categories: Traditional Performance Indices (TPI) and Modern Performance Indices (MPI). TPI indeed include the statistics like mean, variance etc. while reliability is considered among MPI (ShafieeJood et al., 2012). MPI contrary to TPI have direct attention to mobility of system performance under dangerous situations and hence are considered as a very safe option in evaluating water resource systems (ShafieeJood et al., 2012). Hashimoto et al. (1982) introduced reliability as an important index in evaluating the performance of water resource systems which is used for evaluating different scenarios of management and exploitation from water resources. Reliability is the oldest and yet most usable index in water resource management issues and is equal to Equation 1, where possibility (*P*) that system situation (*S*) is in proper conditions (Not-Failure); and when T is total time steps, j is failure counter, d_j is j_{th} failure period and *M* is number of failure events, reliability is estimating using the Equation 2:

$$Reliability = P\{S \in NF\} \quad \dots (1)$$

$$Reliability = 1 - \frac{\sum_{j=1}^{M} d_j}{T} \quad \dots (2)$$

The purpose of reliability is a standard output for exploitation. In irrigation, reliability is the level of trust that provides supply of crops water need (Hashimoto et al. 1982). Allowable reliability in required water supply for the projects of agricultural water supply is made standard in a way that the system is able to supply 95% of water needs of plan in 75% of the cases (Iran's ministry of energy, 2004).

2.4 Vulnerability Index

Parametric vulnerability is similar to shortcomings in the system if it occurs (McMahon, 2006). Vulnerability expresses the severity of system failures and can be defined as 1) average failures (Loucks et al., 2005), 2) the mean of the maximum defects during a succession of failures in the system (Hashimoto et al., 1982), and 3) the probability of scarcity increase in one or more periods of a given limit (Mendozaet al., 1997). Based on the latest relationships presented, the vulnerability criterion is defined as the ratio of the total of scarcity to the number of steps in which the scarcity has occurred divided by the total need of the user j, which can be determined on an annual basis or based on the length of the period on which the need is based (Safavi and Golmohammadi, 2016):

$$vulnerability = \frac{\sum_{t=1}^{T}(D_t^j | D_t^j > 0)}{\left[\underset{t=1}{\overset{T}{N}} (D_t^j > 0)\right] \sum_{t=1}^{T} Demand_t^j} \quad \ldots (3)$$

$100\% \; \forall t = 1, 2, \ldots, T;$

$0 \leq vul^j \leq 100\%$

According to the third definition, vulnerability is the maximum deficiency during the studied periods in which the lack of utility has occurred:

$$vul^j = max \left\{ \sum_{t \in J_i} C^j - Supply_t^j, i = 1, \ldots, T \right\} \quad \ldots (4)$$

In which J_t, ... j_1 are the periods in which the lack of utility or lack of supply has completely occurred; and C^j is a criterion or a limit (the optimum limit), in which the values or source conditions are compared to in the j_{th} period. Courses can be considered on an annual basis or based on the length of the period on which they are based.

2.5 Scenarios

In this study, due to the very low current irrigation efficiency in surface irrigation networks of Dez, the decision was made to use management scenarios including increased efficiency of 5% and 15%. The consumption and demand of water in the Dez basin can be classified into two categories of existing demand (in operation) and new demand (potential). In the process of simulating scenarios, the resources and uses of water in the catchment area of the Dez basin have been used in 2 horizons. The short-term horizons have been used to compile existing demands. In the long-run, water resources structures that are at the stage of study (potential) and have undergone a justification phase are also applied. Table 2 shows the simulated scenarios.

Table 2: Simulated Scenarios

scenario	Time horizon	Simulation conditions
First scenario	short term	Current situation Increasing efficiency by 5% Increasing efficiency by 15%
The second scenario	long term	Current situation Increasing efficiency by 5% Increasing efficiency by 15%

2.6 Modeling and simulation of system

Simulation is the most applied method in evaluating different water resource systems. It is evident that simulation doesn't identify optimal design and policy, but is a rigorous tool for evaluating different plans and policies of exploitation that are identified by simpler optimizing models. In this research, integrated water resources management are selected for simulating water resource system of Dez basin. The possibility of system simulation towards various policies of water resources and performance union (due to considering a full range of options in exploitation, development and management of water resources management) is one main benefit of this method compared to other simulation methods. Ease of amending the model for the intended changes and the ability of performing analyze in each section has made this method more attraction among other different techniques for simulating water resource management systems. With regard to the information and considering the existing complexities in plan, in this study, Water Evaluation and Planning (WEAP) model is used for integrated simulation of Dez basin water resources system that is shown in Figure 2. WEAP model was developed by Stockholm Environment Institute and by specific support of U.S. Army Corps of hydrologic Engineers. This model provides a general flexible framework together with simple graphic user interface for policy analysis. This software is used for evaluating water projects in many countries.

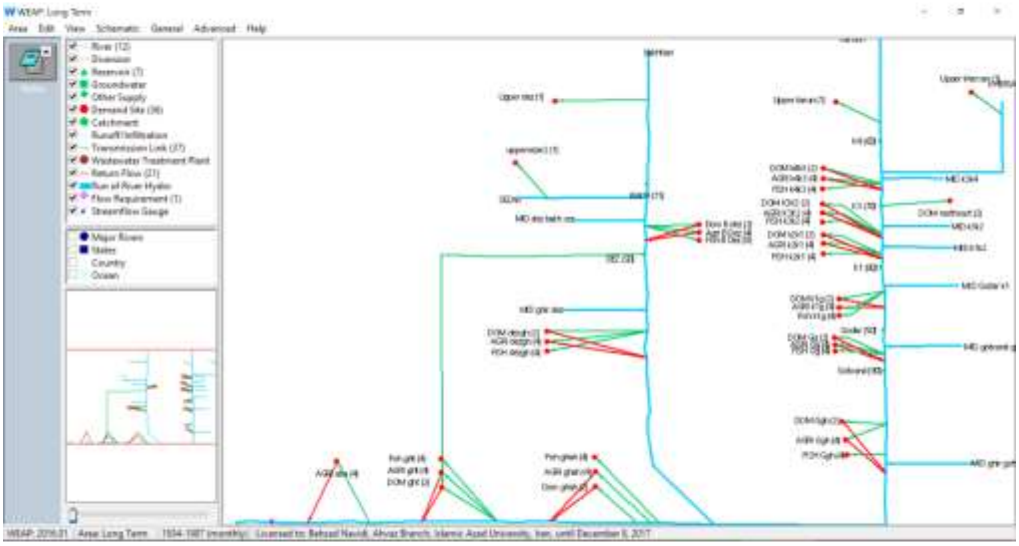

Figure 2: Configuration of water resource system in Dez basin

3. Results and discussion

After complete simulation of the system and entering the required data including the time series of resources and consumption of the catchment basin in each node, the model was implemented for the various scenarios mentioned. According to the calculations, the following results were obtained.

3.1 Reliability index

The reliability of water supply in the initial conditions was estimated to be 71.69%. The simulation results of efficiency gains, which are presented in both short and long horizons, are presented in Table 3 and compared in Figure 3.

Table 3: The results of simulation of scenarios on the reliability index

Scenarios	Time horizon	Simulation	Reliability (percent)
First scenario	short term	Efficiency improve by 5%	71.69
		Efficiency improve by 15%	73.58
Second scenario	Long term	Efficiency improve by 5%	71.69
		Efficiency improve by 15%	71.69

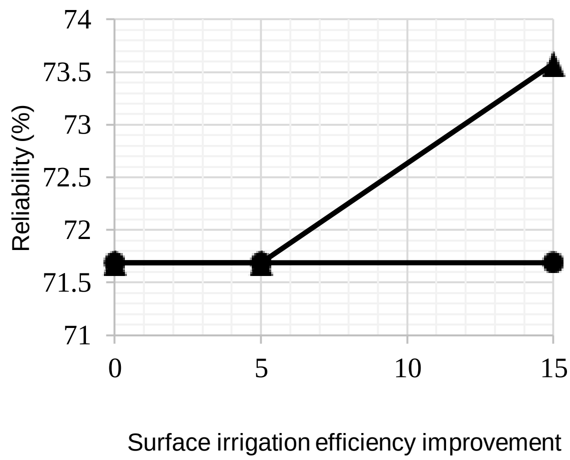

Figure 3: Influences of scenarios on reliability index; Short term (▲) and Long term (●)

As mentioned, by using simulation and modeling for the initial (current) conditions of the catchment basin, the reliability index was estimated to be 71.69%. Considering that in agricultural use, the acceptable rate for the reliability index is above 75%, it can be concluded that despite the low efficiency of irrigation and water allocation much higher than the actual requirements, agriculture in Dez basin has a problem of water supply reliability insufficiency. According to the results of this study, the management scenarios for increasing the efficiency of the short-term horizons (with system requirements in a state that is almost the same as the current one, and potential blueprints and structures have not yet been exploited), with an increase of 5% in irrigation efficiency, reliability has not changed. The occurrence of this was due to the fact that the severity of the failures was so high that they could not be eliminated by increasing efficiency by 5%, and called for increased efficiency and more savings to increase this index. Moreover, the reliability rate increased from 71.69% to 73.58% for 15% increase in irrigation efficiency. The point to keep in mind is that with this slight increase in reliability, a range of years of inadequate supply will be provided. Obviously, the problems caused by water shortages in plants such as water stress or loss of products can be prevented and cultivate sensitive plants with a higher reliablity level or expand the area under cultivation. In such a situation, farmers will be more comfortable with the cultivation of crops.In the long term, the downstream needs have increased considerably (for example, demand for drinking water needed by downstream cities has increased, as well as the hydrological structures of the basin, which are currently under development, have reached the exploitation phase and are in the labor cycle and are consumer of water). It was therefore observed that in such a situation, increasing the efficiency of up to 15% can only maintain the current reliability and cannot increase in any way. Obviously, in the long term, in the absence of improvement in efficiency, over time, the amount of confidence will be reduced instead of being preserved. The large-scale inefficiency of increased irrigation efficiency of Dez network in some specific years on the reliability index of the Dez basin can be for two reasons: First, in the average of long-term discharges of the Dez River, as shown in Fig. 4, natural discharges and 5-Year moving average discharges of Dez River, in some particular years the river input, due to the large droughts it faced, has been far less than expected. Therefore, increasing irrigation efficiency will not have an effect on the reliability of the standard, and under all circumstances, in particular, the system would fail, and reliability could not be achieved in any way. Another reason is the size and amount of water used in the Dez surface irrigation network, which is less than the total level in cycle in Dez basin. Nevertheless, because of the reasons mentioned, it is not possible to ignore the positive effects of increasing network efficiency on improving the reliability of the basin, because, in any case, a slight increase in reliability would ensure the years of failing. A better occurrence of this increase in efficiency can be understood thanks to the vulnerability index.

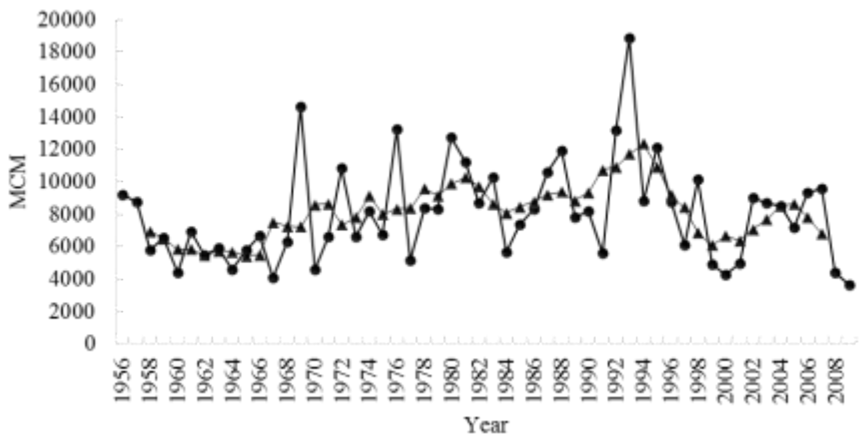

Figure 4: Changes in river inputs to Dez dam; natural discharge (●) and 5-Year moving average discharges (▲)

3.2 Vulnerability index

The vulnerability index largely requires a thorough understanding of the components of the system, and only if we understand these components, we will be able to analyze the behavior of it. The rate of water vulnerability index for short and long term conditions for the catchment basin of Dez was estimated to be 25.70 and 30.46%, respectively. The greater vulnerability in long-term conditions proves the fact that the catchment area will be more vulnerable over time. Table 4 shows the rate of changes in this indicator in different scenarios, these results are plotted in Figure 5.

Table 4: Simulation results of scenarios on vulnerability index

Scenarios	Time horizon	Simulation	Vulnerability (percent)
First scenario	short term	Efficiency improve by 5%	24.01
		Efficiency improve by 15%	22.74
Second scenario	Long term	Efficiency improve by 5%	28.85
		Efficiency improve by 15%	26.00

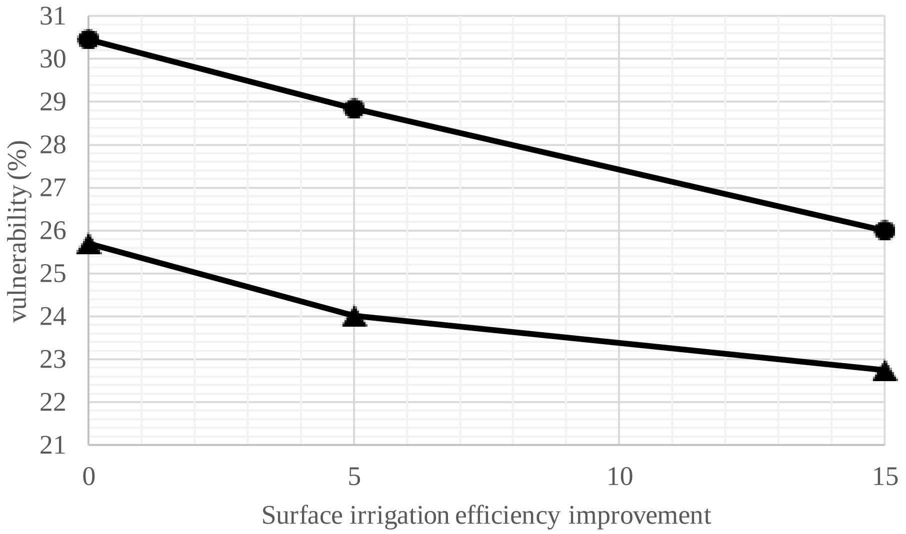

Figure 5: Comparing the influences of scenarios on Vulnerability index; Short term (▲) and Long term (●)

According to the results of the table 4, it can be seen that in the short term, increasing the efficiency can reduce the vulnerability. Reducing vulnerability means that years of non-supply have largely come close to the supply side. In the long term, with vulnerability in water supply of 30.46%, with efficiency improve of 5 and 15%, system vulnerability could be reduced by 28.85% and 26%, respectively. Improving the vulnerability allows farmers to restrain plants that are susceptible to dehydration easily. Reducing the vulnerability of the system, albeit slightly, means improving the system's performance in the face of failures that remains high despite increasing irrigation efficiency.

Conclusion

The purpose of this study was to evaluate the effects of increasing the surface irrigation efficiency on the reliability and vulnerability of water supply in the water resources system of the Dez Basin (agricultural land of surface irrigation system of Dez) in two short and long horizons. To this end, firstly, by considering Dez Basin as an integrated system, management scenarios including 5% and 15% increase in irrigation efficiency were simulated for two short and long horizons. For this purpose, after water studies, the recommended method in FAO-56 and the water requirement for the water pattern required by the water were determined, the overall irrigation efficiency was obtained in irrigation networks in Dez Basin. The results indicated that the amount of efficiency in the Dez surface irrigation networkwas very low and averaged 33%, which also indicated that the reliability of water supply for agriculture in the basin is 71.69%, which is lower than the recommended value. The results of this study indicated that in the short term, with a 5% increase in surface irrigation efficiency, the system reliability could be maintained and increased by up to 1.9% with 15% efficiency. With 5% and 15% increase of efficiency, system vulnerability, reduced by 1.6 and 2.96%, respectively. Simulation results for the long term also indicated that 5% and 15% increase of efficiency had no effect on the improvement of the reliability index, and to improve this index, the system requires more increases in irrigation efficiency. Although reliability index remaining stable and not improving in long-term is a success because in the long term due to increased demand and increase of hydraulic structures in the basin, if there is no increase in efficiency, we will face a severe decline in reliability. In the analysis of the results, it should be noted that increasing the values of the reliability index though a little, in some cases, means the supply of water in the years before the increase in efficiency that was not sufficient and, in contrast, to the use of the amount of stored water resulting from the improvement of efficiency to meet the supply needs of other parts in the basin. The importance of maintaining and improving the reliability index becomes important when by considering the possibility that the climate change phenomenon can make the situation so that the sources of water supply decrease, the role of increasing the efficiency in improving the reliability index in this paper is evident. In the long term, the vulnerability index decreases from 30.46% to 25.58% and 26%, respectively, by 5% and 15% increase of efficiency, respectively.Reducing the vulnerability of the system, albeit slightly, means improving the system's performance in the face of failures that remain high despite increasing irrigation efficiency. The results of this study, while providing integrated vision for basin water resources, will help the government and beneficiaries in the future to make future decisions to address the problems caused by water scarcity and improve the resources and uses of the catchment area.

Acknowledgement

This article is the result of a research carried out at Ahvaz Islamic Azad University. Hereby, authors of this article will convey their appreciation to this university.

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