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Investigating the Effect of Managing Scenarios of Flow Reduction and Increasing Irrigation Water Demand on Water Resources Allocation Using System Dynamics (Case Study: Zonouz Dam, Iran)

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Investigating the Effect of Managing Scenarios of Flow Reduction and Increasing Irrigation Water Demand on Water Resources Allocation Using System Dynamics (Case Study: Zonouz Dam, Iran)

Sistem Dinamiği Kullanılarak Akış Azaltma ve Sulama Suyu Talebinin Artırılması Senaryolarının Su Kaynakları Tahsisi Üzerine Etkisinin Araştırılması (Örnek Çalışma: Zonouz Barajı, İran)

Mohammad Taghi SATTARİ [1*], Rasoul MİRABBASİ[2], Hossein DOLATİ[3], Fatemeh Shaker SUREH[4], Sajjad AHMAD[5]

Abstract

Meeting the healthy nutrition needs of the increasing population in the arid and semi-arid climates of the different regions of the world such as Iran has become very important for the agriculture ministry and water resources managers. In this study, the system dynamics approach was used in the Vensim software environment to allocate the water of the Zonouz dam reservoir for irrigation purposes in the northwest of Iran. For this purpose, the existing surface water resources in the basin and the amounts of agricultural water and environmental water demands were determined and a water allocation plan was developed. In the first stage of the study, it was found that if the existing water resources and demands will not change, the amount of water stored in the reservoir will provide approximately 91% of irrigation water demands and approximately 99% of environmental water needs. The model created in the study was found to be sensitive to reservoir inputs and irrigation water demands. Within the scope of this study, the impact of two different scenarios that may occur as a result of climate change and irrigation management in the operation of the reservoir was evaluated. The decrease in the amount of water entering the reservoir in the first scenario and the increase in irrigation water needs in the second scenario are assumed within the next 10 years. According to the simulation results of the first scenario, irrigation water demands will not be met sufficiently with the decrease in the amount of water to be stored in the reservoir due to the decrease in the amount of water entering the reservoir in the next 10 years. According to the results of the second scenario, in the next 10 years due to possible climate change or if the cultivated area increases due to some new agricultural policies; The amount of water stored in the reservoir will not meet the irrigation demands and there will be water shortage in the system. In this case, it is necessary to make changes in irrigation water management and use new irrigation systems to save water. Based on the findings of the study, it has been observed that the impact of all types of irrigation water policies can be successfully evaluated within the scope of the system dynamics approach.

Keywords: Water resources allocation, System dynamics, Vensim, Zonouz Dam, Iran.

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1. Introduction

Increasing population growth and water use, over-cutting of trees and forests, changing the ecosystem of nature, urban development and pollution production, inappropriate and unskilled agricultural practices are among the factors that cause disruption of the regular water cycle of the planet, which is a serious threat to human society. The arid and semi-arid climate covers a large area of land in Iran and naturally faces many constraints in terms of water resources (Abdi et al., 2017). On the other hand, all available water resources in Iran are not usable and a high percentage of them are salty water (Mirabbasi and Eslamian, 2010). Regarding the unique role of water as an essential element in the economic development of the country, controlling and optimizing the use of existing water resources is of great importance. Since the construction of water facilities requires high costs, neglecting the proper utilization of the land does not only ensure the expected profit from the establishment of the facility, but also, on a grand scale, causing the loss of initial capital and environmental degradation is possible. Lack of systemic attitude in water resources development projects in the country's water basins and allocation of water resources development plans in isolation and point-to-point, regardless of the interactions of water resources development projects in a basin, will be caused big challenges at the basins and the wasting of national treasures. Problems due to population growth and development in how allocated water resources be more complicated day by day, and finding appropriate require better thinking. Available water resources across the globe are used extensively, and population growth and climate change imposes tensions on these vital resources (Baron et al., 2002; Jackson et al., 2001). In order to put together these complex and interrelated components and interact with them and think of ways to manage water resources, it is necessary to develop methods that, in addition to the analysis of the system, can simulate the system as it presents a rough idea of what actually happened or will happen. The science of System Dynamics (SD) makes this possible. Modeling the change in water resources over time dynamically provides a scientifically valid basis for water management strategies (Vines, 2009). System dynamics methods are simple and effective compared to other systems analysis methods and do not require complex mathematics in the system description. The attractiveness of this method is to increase the speed of creating a model, the possibility of group development of models, and the ability to easily modify the model in response to changes in the system (Simonovic and Ahmad, 2002). Also, in this approach, the validity of the model can be measured by various methods such as sensitivity analysis and linear tests. System dynamics analysis is used as a method based on systems thinking to study and improve learning in relation to complex systems. The purpose of this method is to understand the nature of a dynamic occurrence and attempt to implement policies and manage that event (Saysel et al., 2002). This method was originally developed by Forester in 1950 to better understand the strategic issues in complex dynamic systems (Forrester, 1961). This method predicts the behavior of system by considering the relationships among its components. These patterns are a way of understanding the behavior of complex systems over time. What distinguishes system dynamics from other methods is the use of feedback loops and rate and state variables that help in understanding the behavior of the system. The basis of this method is to recognize the structure of the system (nonlinear relationships, delays, and feedbacks) in determining the behavior of the system in terms of the recognition of each component (Forrester, 2007). The system dynamics has so far been used in various scientific fields such as the environment (Feng et al., 2013; Ding et al., 2016), sustainable development issues (Yang et al., 2015), environmental management (Dace et al., 2014), environmental and ecological modeling (Weller et al., 2014) etc. The first model of system dynamics for urban water management has been developed by Grigg and Bryson (1975) and Grigg (1997). They analyzed the dynamics of water resources in the Fort Collins metropolitan area. Keyes and Palmer (1993) used the SD method to simulate a drought condition. Fletcher (1998) used this method as a decision analysis method for water deficit management. Simonovic and Fahmy (1999) used the above method to evaluate long-term water resources and to analyze applied policies in the Nile River Basin in Egypt. Royston (1999) used the above method to provide water demand and exploit a multipurpose reservoir. Subsequently, system dynamics models were used by many researchers to manage water resources in different parts of the world (Ryu et al., 2012; Xi & Poh; 2013; Wu et al., 2013; Kotir et al., 2016; Sun et al. , 2017).

In Iran and in the World, a numerous number of researches have been done using the system dynamics approach. For example, In this section, we will mention some articles that have been working on reservoirs. Rouzegari et al, (2019) was first estimated, using the flow duration curve shifting method (FDC Shifting) the environmental water demand of the Mahabad River in the Urmia Lake basin in Iran. Secondly, the optimal operating model of the reservoir was developed with the goals of decreasing the deficiencies and considering the downstream demands of the reservoir. Sattari et al, (2013) has been devised a method to make available the maximum amount of water for irrigation, drinking, and the flow regime of Sofi Creek. The optimal performance of the Eleviyan Dam was evaluated based on reservoir inflows. Sattari et al, (2012) used 4 different datasets of monthly amounts of water to be released from the Eleviyan irrigation reservoir in Iran as inputs in a data mining model; "if–conditional" operating rules were determined as outputs. Sattari et al, (2009) the efficiency of the Eleviyan irrigation dam system was investigated in three phases by setting up the optimization model that maximized the water release for irrigation purposes after municipal water need were met. In this study, water use performance indicators in Kızılırmak Basin Irrigation Schemes for the years were 2003-2005 were determined; the results were discussed and evaluated. Çakmak et al, (2007) were determined water use performance indicators in Kızılırmak Basin Irrigation Schemes for the years were 2003-2005; the results were discussed and evaluated. Çakmak et al, (2014) developed four benchmarking performance indicators by International Water Management Institute (IWMI) indicating incomes per unit area and water and the other water use efficiency indicators were used together to assess the water use efficiencies of irrigation schemes over transboundary basins.

Nasseri et al. (2009) developed a model based on the system dynamics for Shahr chay dam reservoir and underlying aquifer in Urmia, Iran. In that model, the interaction between demand and supply of drinking, industrial and agricultural water uses from both surface and ground water resources created a complex system. The results of the model showed that if the sewage collection system is implemented in Urmia and the sewage reaches zero, the total water supply will be provided from the reservoir water and the irrigation efficiency will reach 41 percent, and much of the groundwater storage will be reduced. Alami et al. (2014) used the SD method to optimize the water management of Golak Dam in Zahedan, Iran. The results of their research showed that using the system dynamics approach, it is easy to see the effect of applying different scenarios and management policies on the allocation of water resources and based on which decisions were made. Zarghami et al. (2016) used a system dynamics approach to develop a decision-making system for the operation of Yamchi Dam in Ardebil province, Iran under the influence of climate change. They concluded that this method could be used in cases where the development of a policy or decision was made in a critical situation. Gohari et al. (2017) used the system dynamics method to investigate different strategies for managing water resources under the influence of climate change in the Zayandeh Rood River Basin, Iran. They divided the existing system into three hydrological, agricultural and socioeconomic sub-systems, and used the system dynamics to analyze and evaluate the adaptive management strategies for climate change.

Shao and Yang (2009) investigated the historical evolution of the water resources allocation system in the Yellow River basin of China. Based on the concept of water use flexible limit to water shortage and actual water use data from 1988–2006, a set of flexible limits to water shortage adapted to the Yellow River basin has been proposed.

Xie et al. (2018) was developed an inexact two-stage stochastic downside risk-aversion programming for regional industrial water resources allocation under considering system return-risk and various environment control strategies. The model is applied to a real case of industrial water resources allocation management in Chongqing city, China, where regional industrial system has faced with lots of difficulties and complexities in water resources utilization and water environmental protection. The results indicated that the total pollutants emission amount control and the expected revenue risk can be used as effective measures for regional industry structure adjustment from terminal environmental and macro-economic perspective.

There are some softwares which released for creating water resource allocation models based on the system dynamics approach. One of these softwares is Vensim (Venata systems, 2000). Vensim software is a graphical object-oriented modeling tool that is capable of embodying, processing, simulating, analyzing and optimizing dynamic models. Vensim provides a simple and flexible way of simulating loop models and flow diagrams. Many researchers have used this software to model water resource allocation. Zarghami and Akbariyah (2012) simulated the urban water system of Tabriz based on the system dynamics approach using the Vensim software. Sahin et al. (2015) used the Vensim software to simulate the South East Queensland water system in Australia and review economic feedbacks. Fazel Modares et al. (2012) provided the optimal allocation of water resources to the Alavian dam using the Vensim model. The results showed that the dam provides downstream area demands at a desirable level. Arshadi and Bagheri (2013) used the Dynamics Vision System and Vensim Software Approach to analyze the status of the Karun basin water resource system from a sustainability perspective. Babaian et al. (2016) analyzed the vulnerability of the water resources system in Rafsanjan to water deficit using the water accounting framework. In order to investigate the impact of different policy options in existing conditions and create an environment for decision making, using the SD approach, the economic-water resource model was developed by the Vensim software.

In this study, the system dynamics approach was used to simulate the water resources of the Zonouz Chai basin and providing different scenarios for optimal allocation of Zonouz Dam water resources

.2. Materials and Methods

2.1. The study area and used data

Zonouz Dam is located in the Aras River basin, North-west of Iran. The basin of the Aras River is the basin borders the countries of Azerbaijan and Armenia with the countries of the north and having a common frontier with Turkey. The climate of this basin is mainly influenced by the polar front and moderate Mediterranean air masses (Jamab Consulting Engineers Company, 2005). Zonouz Dam is located 24 km north of Marand city and 100 km northwest of Tabriz city (Fig. 1). Zonouz River originates from the Sultan-Zanjir heights (Sultan Sanjar) and from the mountains of Daghdi, Ghazal Daghi, Odaghi, and Bughodadaghi, and flows east-west direction. After passing through the city of Zonouz and joining the Qotur River, the river flows through the Aras River to the Caspian Sea. The area of the Zonouz basin is about 45.3 km2 and the average annual discharge is 11 million cubic meters. The average annual sediment is about 194000 cubic meters, and the average annual precipitation and evaporation of free water surface at the dam are measured 386 mm and 922 mm, respectively (Jamab Consulting Engineers Company, 2005). Also, the time series of the monthly discharge of the Zonouz River at the Chercher station is shown in Fig. 2. It should be noted that the horizontal axis of this chart is based on the month of October 1974. The required water for agricultural lands and gardens in Marand and Zonouz is being provided from Zonouz Dam within the modern network irrigation and traditional drainage. Providing the irrigation demand by this dam, especially during the drought periods, has been able to maintain the farmer’s livelihoods of the region well.

Figure 1. The geographic location of Zonouz Dam

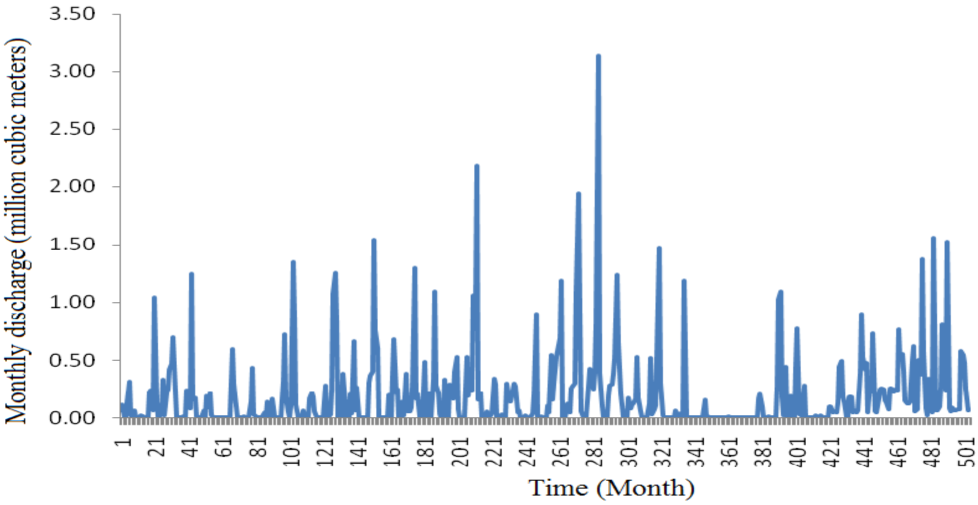

Figure 2. Monthly discharge time series of Chercher Station (1974-2016).

In this study, the river discharge and precipitation data in the period of 1974 to 2016 were obtained from the Regional Water Company of East Azarbaijan and Islamic Republic of Iran Meteorological Organization (IRIMO). The surface water abstraction data of the region are collected every few years by the regional water company, which includes information such as geographic location of exploiting source, exploitation water flow and exploiting time. The data related to the cultivation of irrigated agricultural land, including irrigated agriculture and gardens, GIS maps for vegetation cover and water information, each plus the related levels, were provided by the Agriculture Jihad Organization of East Azarbaijan Province.

2.2. System Dynamics method

The basis of the simulation method of system dynamics is based on feedback and object-oriented events. One of the important concepts in the system dynamics approach is the law of continuity, which is the basic concept of routing in the reservoirs. In this method, four tools of storage, flow, interfaces, and converters are used for modeling, and the expert's mentality focuses on causation and eventual charts and ultimately the storage and flow (Simonovic et al., 1997; Sterman, 2000). System Dynamic models allow the inclusion of quantitative and qualitative variables simultaneously in the system. In mathematical models, it is not possible to edit qualitative parameters. In dynamic models, by writing inaccurate equations for qualitative variables and numerical simulation, the effect of these variables on the whole system is considered (Forrester & Senge, 1980). In the Vensim software, the relationships between system variables describe and define by connecting words by flash. After defining the above relations and constructing the model, all aspects of the behavior of the system can be able to simulate. The Vensim environment makes users needless from the mathematical basis form also the language details. This software can simultaneously solve nonlinear equations among several variables. In this software, the graphs are constructed with a series of first-order differential (often nonlinear) equations, which are solved by the Euler or Runge–Kutta methods. The modeling method in this software is to make the progress of the generalities in more detail so that the functions and components of the connection are gradually increased so that a complete model for execution is prepared.

2.3.Modeling in the Vensim environment

Modeling in Vensim software includes the following steps:

- Collection of data and required information

- Data processing and preparation

- Determine and calculate the amount of water resources

- Determine and calculate the water demands in different sectors of consumption

- Preparation of information for use in the Vensim model

- Creating model in the Vensim software environment

- Analysis of the results of the model

The key stage in modeling is the proper definition of the conceptual model of the desired area. That is, firstly, the components of the basin balance should be precisely determined. Afterward, the amount of each component of the balance sheet should be precisely determined. After estimating the inputs to the reservoir and the water demands that can be provided by it, simulation and preparation of the basin model begin at the monthly scale. At this stage, the amount of water entering the reservoir is considered in terms of its upstream designs. The amounts of resources and expenditures in the basin of each dam are entered into the model on a monthly basis and the performance of the basin in terms of the percentage of time supply and volume of drinking, agricultural, environmental, and industrial demands in different drainage conditions of the basin as output of the model is obtained.

The purpose of the construction of each dam is to provide a set of demand types such as drinking, industrial, and agricultural demands that are calculated for the basin of each dam and considered as the planning needs of that dam. Also, environmental demands should be considered in designing each dam. Zonouz Dam has been designed and constructed with the aim of providing agricultural and environmental demands. The amount of agricultural demands of this basin is presented in Table 1.

Table 1. Average monthly agricultural demands (Million Cubic Meters)

Month	October	November	December	January	February	March	April	May	June	July	August	September
Agricultural needs	0.33	0.24	0.0	0.0	0.0	0.0	0.48	0.59	0.43	0.12	0.11	0.08

Each dam after exploitation should meets own downstream environmental demands. In the present study, the Montana (Tennant) method has been used to estimate the environmental need of the Zonouz Dam (Tennant, 1976). According to this method, after calculating the average input of the dam reservoir for months of the year during the period of discharge, a percentage of that, which varies for the first and second six months of the year, is considered as the environmental demands of the dam in the model. Table 2 shows different percentages of the river discharge based on different conditions. In this study, for the Zonouz Dam, 30% of the river discharge in the first six months of the year and 10% of the river discharge for the second six months of the year were considered as an environmental demand (Table 3).

Table 2. The amount of environmental demand based on the Montana method (Tenant, 1976)

Quality of aquatic life	The minimum share of the long-term average of the river	
	October to mid-April	From mid-April to September
Ideal situation	60-100	60-100
Great	40	60
Excellent	30	50
Good	20	40
acceptable	10	30
weak	10	10
Severe shortage	Less than 10	Less than 10

Table 3. Zonouz Dam environmental demands in different months of the year (Million Cubic Meters)

Month	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Average annual discharge	0.07	0.14	0.13	0.11	0.11	0.24	0.54	0.52	0.24	0.09	0.10	0.02
Environmental need	0.007	0.014	0.013	0.011	0.011	0.024	0.162	0.157	0.072	0.026	0.029	0.006

To simulate with Vensim software, it is necessary to first design the structure of the model (definition of system variables, connections, and relationships between the variables mentioned above) and after entering the relevant data in the software, implementation and simulation of the model are performed, so that the output results to be achieved. It is necessary to ensure that the time of the model is set before the model is executed so that the model is equivalent to the number of months of the length of the statistical period. Referring to the output file of the simulation model, it can be calculated by comparing the input data of different demands and the output numbers of the supply corresponding to each demand, the volume and time percentages of the supply. It should be noted that the determination of the amount of water allocated from water resources to every demand and uses of the waters in the watershed is based on the priority and with regard to the quality constraints and the possibility of the transfer of appropriation from one consumption to other uses.

In this study, after collecting hydrologic and meteorological information of the area, the conceptual model of the Zonouz Dam and the basin was identified and the Causal Loop Diagrams of the basin were drawn in the Vensim software environment. Figure 3 shows the cause and effect diagram of the Zonouz Dam as feedback loops. In this Figure, the amount of storage in the dam of the disabled dam is the input variables, evaporation, leakage from the wall and the dam, release, and overflow. In this model, the volume of the reservoir is represented by the storage variable (state variable), and the input flow, evaporation values, output flow, and overflow values are shown as a flow (rate) variable. The amount of overflow from the reservoir of the dam is calculated according to the input, output and height values equal to the maximum volume of the reservoir. Output flows are determined based on operating policies and downstream requirements. This amount is deducted from the sum of the input flow and the reservoir storage volume with reservoir losses and leakage amounts. The residual volume is compared with the equivalent volume of the maximum water heights in the dam reservoir and the excess is extracted from the reservoir of the dam as the overflow. It should be noted that the water infiltration values from the reservoir floor due to the lack of measured data are not included in the model. Therefore, in losses, only the amount of water leakage from the walls and the foundation of the dam and evaporation from the dam reservoir surface are considered. In the next step, the required data were entered into the model. These data include the long-term series of monthly discharge into the dam reservoir, the monthly evaporation from the reservoir, the surface-volume-height of the reservoir, the maximum reservoir volume, and the dead volume of the reservoir, the monthly distribution of agricultural demands and the environmental demands.

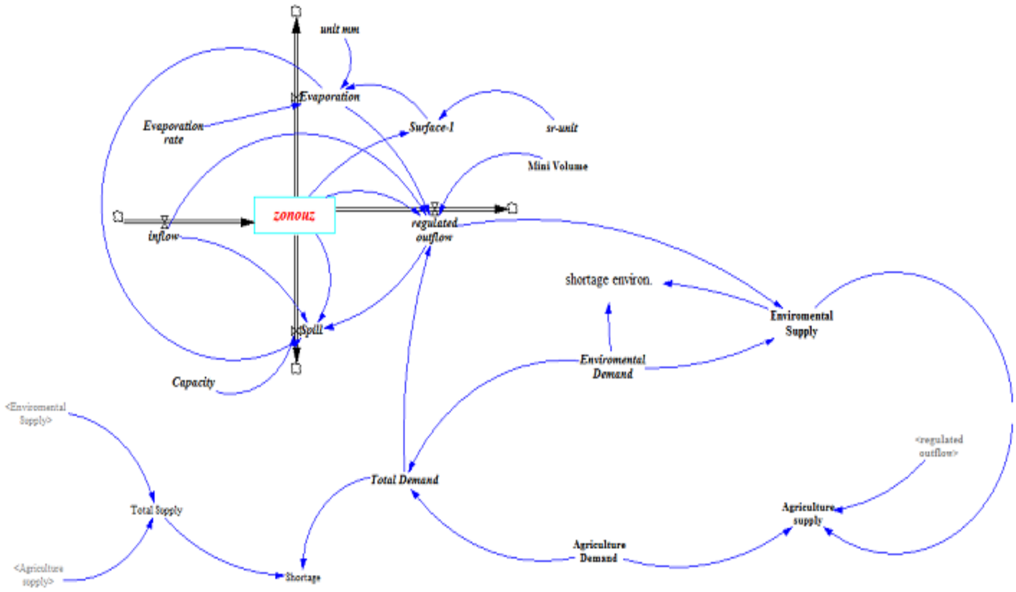

Figure 3. The Causal Loop Diagram of the Zonouz Dam

It should be noted that the development of withdrawals from water sources during different years in the basin has its effect on the recorded catches at the station. In simulating water resource development plans, it is assumed that the river discharge regime in the position of hydrometric stations in the coming years will be similar to previous years. Therefore, it is necessary first to eliminate the effect of upstream catchments on water resources registered at hydrometric stations, which will reduce river discharge in the position of the hydrometric station in the coming years, and then use it to simulate water development plans. For this purpose, the Trend removal method was used.

At the design stage of the dam reservoir model, all the input and output parameters were coded to the Zonouz Dam reservoir with respect to their relationship with each other in the Vensim software environment. Then for each of the parameters, according to the program's standard, the flow or storage property was given, and the variable or constant form was given, and for the parameters that are in series (such as the input flow), the required data were entered. For the rest of the parameters, the conditional formula "if-then" was written to run the model using the relationship that they have together. In the calibration step, the volume of the reservoir was investigated in terms of balance.

3. Results and Discussion

After constructing the Zonouz Dam model in Vensim software, and also collecting and analyzing the data needed to model the dam and define the data to the model, simulation of the performance of this dam by the software and the results of the behavior of each variable of this dam is presented in following during the simulation period (water years 1974-1975 to 2015-2016).

In order to calculate the level and height of the water stored in the dam reservoir at any time step, it is necessary to estimate the volume-level, the volume-height relationship of the dam reservoir and define them to the model. For this purpose, a quadratic equation on the volume-level of the reservoir of the dam was plotted and on the volume-height of the dam reservoir of a cubic equation fitted and entered the model. In the following, the minimum and maximum values of the reservoir volume were entered into the model. The minimum volume of the reservoir volume is the same as the dead volume of the reservoir, which is 0.6 million cubic meters for the Zonouz Dam. The maximum volume of the dam reservoir is the same as the total volume of the reservoir or the volume of the reservoir at the normal level, for which the dam is 6 million cubic meters. Evaporation from the reservoir surface of the dam can be calculated with the information of the evaporation rate and reservoir surface by the software.

Figure 4 shows the variation in the volume of water entering the reservoir during the years 1974-2015.

According to Fig. 4, it is observed that in the 340-380 months the flow in the river is low because of occurring the drought. It is also seen in Fig. 4 that in the months of 21, 130, and 400 the amount of flow in the river was high. Similar to the graph for changes in the volume of water stored in the reservoir, changes in the surface water behind the reservoir, the amount of evaporation from the reservoir, the amount of outflow discharge from the dam, the total demand for water, and here are just some of them for the abbreviation is brought.

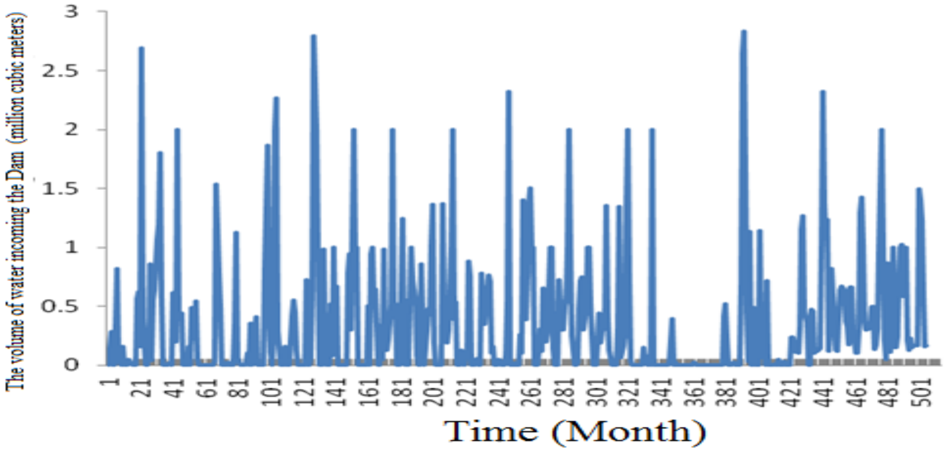

Figure 4. Changes in the volume of water incoming the reservoir during the years 1974 to 2016

3.1.Calibration of the model

The important steps of modeling, are calibration, sensitivity analysis and verification of the model. At this stage, the behavior of the model is compared with the observed behavior of the dam. To ensure the behavior of the reservoir of the dam, the simulated reservoir volume is compared with the volume of the reservoir recorded on the site. After correcting and adjusting of parameters and relationships, the calibrated model is considered as the actual system display in nature. For this purpose, the reservoir storage volume information was used for the period of 72 months during the water years 2009-2010 to 2015-2016. Information about these years has been entered in the form of historical data and the reservoir volume has been compared with the values measured at the dam during these periods (Fig. 5). As shown in Fig. 5, the amount of water stored in the reservoir obtained from the simulated model are in good agreement with the actual storage capacity of the reservoir during the operation period. Also, it is concluded from the Fig. 5 that in the years 2011 and 2014 the amount of reservoir obtained from the simulation with the actual storage volume of the reservoir is approximately equal, indicating better management and utilization in these years.

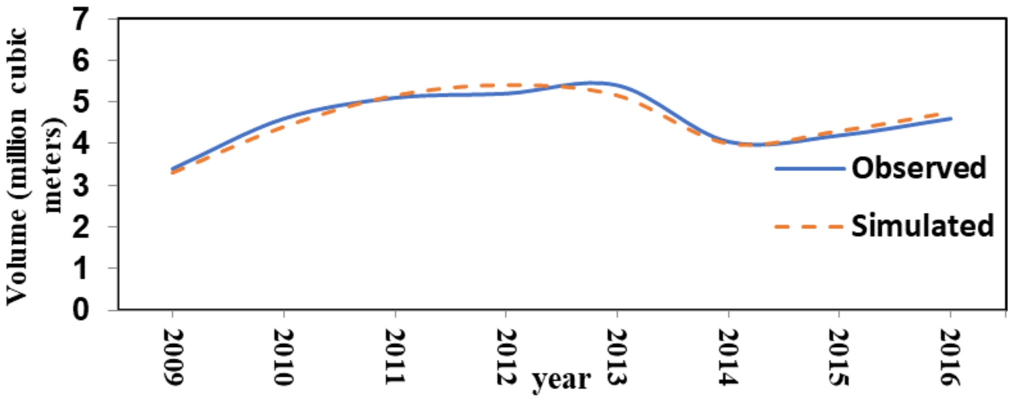

Figure 5. Comparison of the volume of stored water in the reservoir based on the simulated model and observed data

Figure 6 shows a comparison of the behavior of the simulated model and the actual behavior of the dam in the periods of operation from the point of view the amount of outflow. As shown in Fig. 6, the amount of outflow from the reservoir simulated by the model is consistent with the actual outflow of the reservoir during the operation period, which indicates the efficient management and operation of the Zonouz Dam during this period. After calibration of the model, the sensitivity of the model to the parameters of the volume of input into the reservoir, the evaporation amount from the reservoir, water leakage rate, agricultural and environmental demands were analyzed. After each simulation step which was done by decreasing or increasing the desired values relative to their base state, the existing error between the data was calculated for the reviewed variables. The results showed that the generated model is more sensitive to the input inflow variable than the other variables. Agricultural demands are at the next rank. This means that the simulation of the dam reservoir should be more accurate in measuring the data related to these variables.

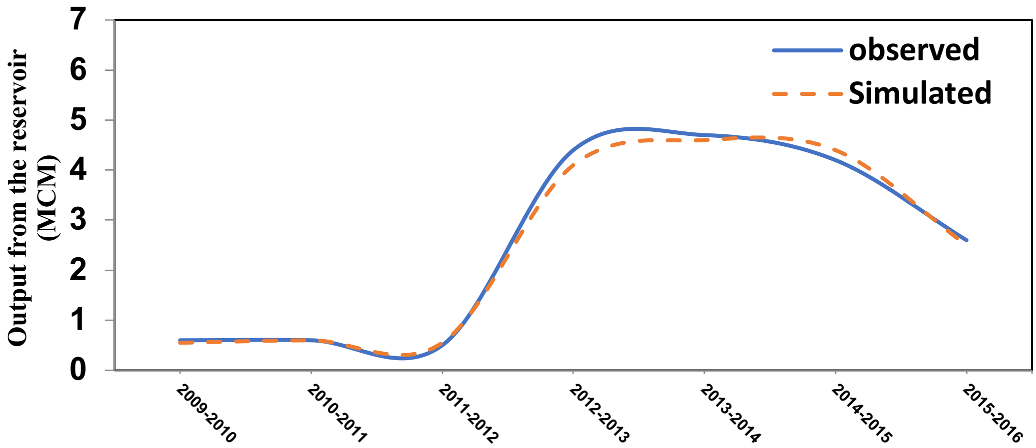

Figure 6. Comparison of outflow water from the reservoir based on the simulated model and observed data

3.2.Model Execution Results

Figure 7 shows the amount of water needed to meet all the demands, including agricultural and environmental demands. The amount of deficiency in supplying agricultural and environmental demands is presented in Figures 8 and 9, respectively. As shown in Figure 8, the system was unable to meet the agricultural demand in the months of 80 to 100 and between 350 and 390 months, with a deficit of 7.8 million cubic meters. In the event of a shortage of agricultural water supply, it is possible to reduce the water demand by cultivating the crops that are resistant to water scarcity, using pressurized irrigation methods or using groundwater resources. As shown in Fig. 9, the system was unable to meet the environmental demand in the 80 to 100 months and 350 to 390 months and had a deficit of 0.2 million cubic meters.

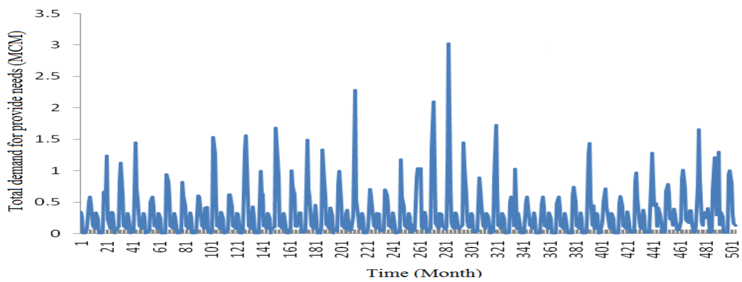

Figure 7. Total water demands for providing all the needs

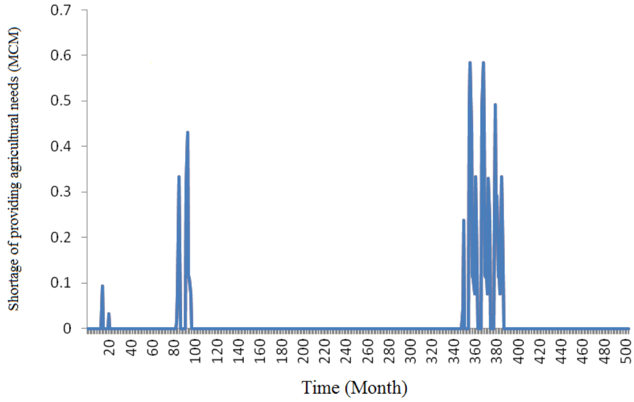

Figure 8. Shortage of providing agricultural needs

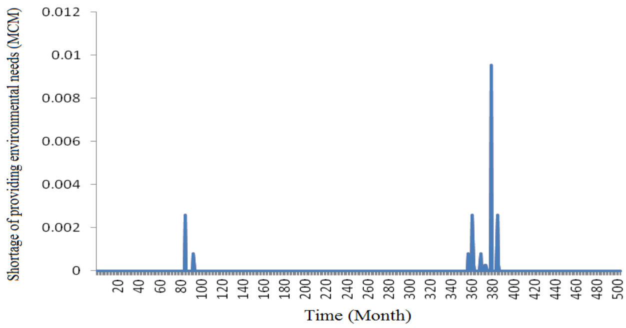

Figure 9. Shortage of providing environmental needs

In Figure 10, the amount of water released from the Zonouz Dam reservoir has been shown to provide demands of the dam downstream. This amount of water includes agricultural, environmental and overflow water needs. This amount of discharge water is proportional to the incoming flow amount of the dam. As seen in Figure 4, in the period between 340 and 380 months, a drought occurred. At the same time, the outflow of the dam has been greatly reduced.

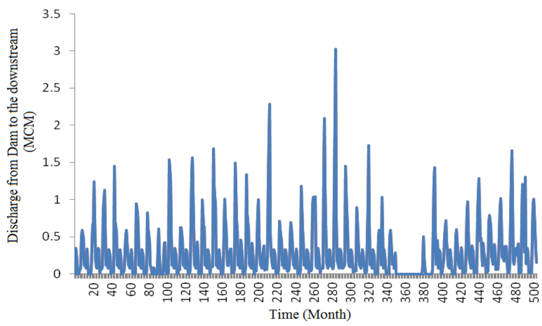

Figure 10. Amount of Discharge from the Zonouz Dam to the downstream

According to the standard, how to evaluate the allocation of water resources for water resources development projects, the acceptable range of volumes and times, the supply of various demands for environmental requirements is 90 to 100 percent, and the agricultural needs are 80 to 100 percent. The results of calculating the volumetric supply percent of different demands for the Zonouz dam are presented in Table 4. According to Table 4, the percentage of agricultural demands in the Zonouz Dam are equal to 91.24% and the volume of environmental demand is equal to 99.6%, which are in accordance with the above standard and within the acceptable range.

Table 4. Amount of volumetric supply requirements in Zonouz Dam from 1974 to 2016

Needs	unit	amount
Agricultural needs	MCM	99.4
Environmental need	MCM	57.7
Total need	MCM	157.1
Agriculture supply	MCM	90.7
Environmental supply	MCM	57.5
Total supply	MCM	148.2
Agriculture shortage	MCM	8.7
Supply of agricultural needs	%	91.2
Environmental shortage	MCM	0.2
Supply of volumes of environmental demand	%	99.6
Total shortage	MCM	8.9

The deficit / excess values of the Zonouz Dam reservoir system are based on the results obtained from the simulated model and the actual operation of the reservoir between the years 2009-2010 to 2015-2016 is presented in Table 5. According to the results of Table 5, it is noted that the system was deficient in the years 2009-2010, 2011-2012, 2015-2016 and in the water years 2012-2013 until 2014-2015 the amount of water was abundant (more than reservoir capacity) and overflowed out of reach. The results in Table 5 show that during the exploitation period, a total of 11.16 million cubic meters was equivalent to a shortage (61.8% of supply needs) and 7.66 million cubic meters of excess water was out of reach and wasted. In general, the results show that the exploitation policy of the Zonouz Dam is inappropriate during the exploitation period and needs to be reviewed.

Table 5. The results of deficit/surplus in the simulated and observed period in water years 2009-2010 to 2015-2016

water Year	Observations Output (MCM)	Model Output (MCM)	Needs (MCM)	Shortage/surplus (observations) (MCM)	Shortage (model) (MCM)
2005-2006	0.53	3.46	3.46	-2.93	0
2006-2007	0.56	4.65	4.65	-4.09	0
2007-2008	0.38	3.60	3.60	-3.22	0
2008-2009	5.69	4.29	4.29	+1.40	0
2009-2010	8.90	4.99	4.99	+3.91	0
2010-2011	7.78	5.43	5.43	+2.35	0
2011-2012	3.07	3.99	3.99	-0.92	0
Total	26.91	30.40	30.40	**surplus/-11.16 = Shortage** +7.66 =	0
Percentage of supply needs = % 61.8					

3.3.Simulation results of various management scenarios

After creating and calibrating the model, the allocation model of different scenarios can be implemented and according to their results, an optimal way to exploit the water resources of the dam was achieved. Here two of these scenarios have been investigated.

3.3.1.First scenario: the effect of reducing the volume of water entering the dam reservoir in the next 10 years on how to allocate dam water resources

In the first scenario, it was assumed that the incoming flow of dams would drop about 20% as a result of the occurrence of droughts. In this case, as it is deduced from Table 6 and Fig. 11, the storage volume in the Zonouz Dam reservoir is reduced and it is in difficulty to meet the downstream needs and the system will face a deficit of 23.2%. According to Fig. 11, from 500 to 540 months, the storage capacity of the reservoir is significantly reduced. It is natural that during these years the system will suffer from a shortage and for compensating this water shortage, it needs to reduce the cropping area, or use pressurized irrigation systems, increase the water use efficiency or, if possible, use groundwater resources.

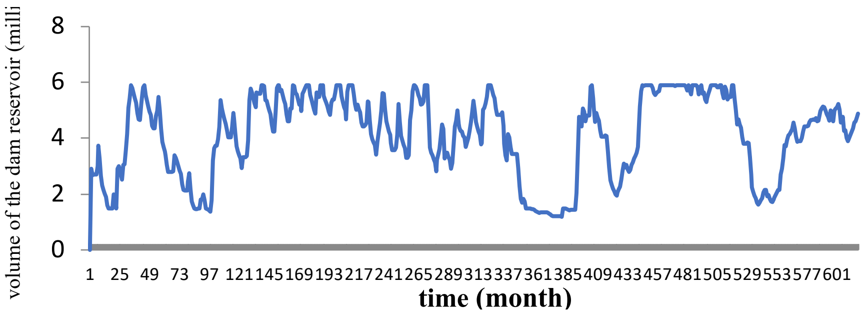

Figure 11. Changes in the volume of water behind the reservoir of the dam from 1974 to 2025 by applying the first scenario

Table 6: Provisional amounts of volumes of each type of demands for the first scenario

Needs	Unit	Amount
Agricultural needs	MCM	123.1
Environmental need	MCM	74.5
Total need	MCM	197.6
Agriculture supply	MCM	94.5
Environmental supply	MCM	66.8
Total supply	MCM	161.8
Agriculture shortage	MCM	28.6
Supply of agricultural needs	%	76.8
Environmental shortage	MCM	7.7
Supply of volumes of environmental	%	89.7
Total shortage	MCM	36.2

According to the results of Table 6, we can see that the percentage of agricultural needs and environmental requirements are not within the acceptable range. With a 20% drop in incoming water in the next 10 years, the system will face with a 23.2% water deficit in providing agriculture demands and 10.3% in the environmental needs.

3.3.2.Second Scenario: the effect of change in demands on dam operation planning

In the future, in order to develop the agricultural land in the region, a new agricultural plan is needed; changes in the dam model can be quickly evaluated by the effect of these changes on the allocation of water resources of the dam. Therefore, in this scenario, it is assumed that an agricultural demands increase by 20% in the next 10 years. Under these conditions, the average changes in the volume of water behind the reservoir of the dam in each month during the years 2016 to 2025 for the two modes of non-change in the requirements of the dam planning needs and the increase in the requirements for dam planning needs is shown in Fig. 12. According to this figure, it is clear that with an increase of 20% in agricultural demand, the amount of water stored in the reservoir will decrease in all months of the year.

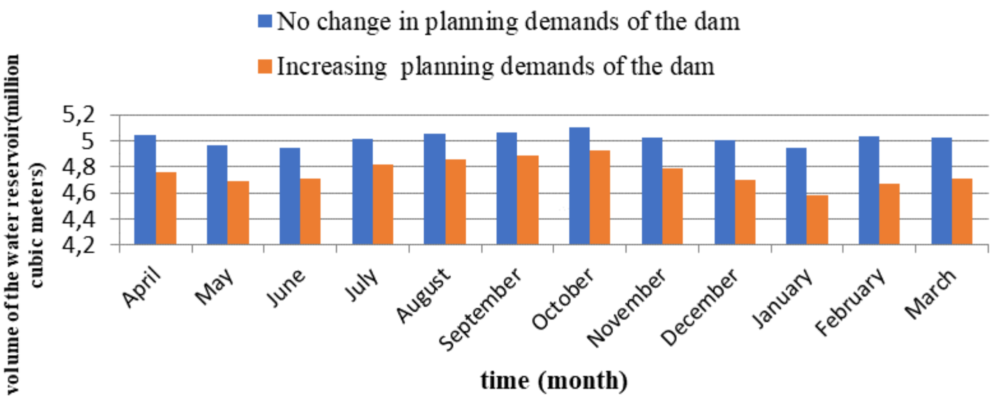

Figure 12. Comparison of the average volume changes of water volume behind the reservoir of the dam in the years of 2016-2025 with and without applying second scenario

4. Conclusions

In this study, the Zonouz Dam simulation model was developed with the system dynamics approach in Vensim software and with its help, the dam water resource allocation plan was investigated. For this purpose, firstly necessary information, including river flow data at the entrance to the dam and evaporation rate from the free surface water was collected at the site and the water demands were determined in the study area, which included agricultural and environmental demands. This data was used as input for modeling. Then the created model was calibrated and the sensitivity analysis was performed on the input variables in the model. The results showed that the created model had the highest sensitivity to the inflow to the reservoir and then the agricultural demands. The results of the implementation of the model showed that the percentage of agricultural demands in Zonouz Dam are equal to 91.24% and the percentage of environmental demand is equal to 99.6%. Subsequently, two different scenarios, including the decrease in the volume of water incoming the dam reservoir and the change in the amount of dam planning need for the next 10 years, were determined for the model and its results investigated. The results of the first scenario on the model showed that by decreasing the amount of water incoming the dam reservoir in the next 10 years, the volume of water behind the reservoir of the dam will be significantly reduced, while the volume of supply of different demands will be reduced by the dam reservoir. The results of the second scenario showed that if the amount of water needed in the dam, which includes agricultural demands, will increase by 20% over the next 10 years due to climate change or an increase of agricultural land, the volume of water stored in the reservoir will decrease in all months of the year. The results of this study showed that after constructing a dam model in Vensim software, simply and quickly, the effect of different scenarios on the allocation of water resources of the dam could be studied.

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