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Water resources sustainability under climate variability and population growth in Iran: A system dynamics approach

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ABSTRACT
The change in availability of water resources has a dynamic behavior and is influenced by many factors such as population growth and climate variability over time. Understanding the impacts of such factors on water resources vulnerability is essential for ensuring the sustainability of future water resources. In this study, a water resources sustainable index is built using a system dynamics model to assess the effects of different scenarios at the K*owsar* dam basin in southwestern Iran where managing water resources is serious challenging due to periodic drought. Based on the baseline scenario, the total population, as well as total water demand, will increase and water supply will decrease throughout the simulated period. Therefore, the imbalanced supply-demand of water can cause the water system vulnerable. In this regard, water management policies should concentrate on the demand side of water to address the problem of water resource shortage in a good manner. Although pessimistic climatic conditions along with population growth put the water system in the worse situation of water availability, where the demand control policies likely help meet the increasing water demand. Compared to the pessimistic conditions, the water sustainability index improves in normal and optimistic conditions. The highest sustainability index was obtained after controlling water demand in optimistic weather condition. Consequently, the government should provide a context in which people learn to control their daily water consumption. Also, it suggests that we can conserve water resources in the agricultural sector with conservation policies.

Keywords: Sustainability, Water system, System dynamics, Kowsar dam basin, Iran.

INTRODUCTION
Water is essential for people's daily life, agricultural irrigation, fish farming, and manufacturing (UNIDO 2003, Bates *et al*. 2008). However, this vital resource is faced with several stresses in quantity and quality. Among the others, climate variability and population growth have resulted in water scarcity in many countries especially in the arid regions (Jury & Vaux 2005, Milly *et al*. 2008, Kalra & Ahmad 2009, Kalra *et al*. 2012). The increasing gap between supply of and demand for water resources can make the water system more vulnerable (Arnell & Liu 2001). Therefore, the most challenging issue in water resources system is to achieve a balance between supply and demand (Xiao-jun *et al*. 2012). Water scarcity problem threatens around 80% of the world's population (Vörösmarty *et al*. 2010, Mancosu *et al*. 2015). Iran, as a semi-arid country, has experienced a lot of water scarcity challenges. Average precipitation in Iran is about 250 mm per year, which is less than one-third of the average annual precipitation at the global level. Also, 75% of the precipitation falls at unnecessary time when not needed by the agricultural sector. Provisioning of water is vital during the critical periods when demand for agricultural water is high and basically if precipitation is not enough to meet such a demand (Nikolaevich Makarov *et al.* 2020, Ashtiani *et al*. 2016). On the other hands, population is growing rapidly and thus increasing water demand in Iran (Madani 2014). The average population growth rate in Iran during 199-2000 was 1.76 % and deceased to 1.25 % in 2010-2015. However, in all these periods, Iran's population growth rate has been above the global average (UNDATA 2017).

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The dramatic population increase and climate variability towards being warming and lower precipitation in Iran have reduced per capita renewable freshwater availability. In recent years, per capita water resources have reached about 1,000 cubic meters, which is about one-fifth of its value in 1971 (Madani 2014, Abbaszadeh & Sisman, 2021). In addition to population growth, the recent droughts have increased the water shortage in Iran. As far as population growth is considered, the effects are not limited to increasing demand for drinking fresh water, the growing population is associated with an increasing demand for agricultural products as well, especially that some strategic food items, e.g. wheat, are provided at subsidized prices and the Iranian government insists on their domestic supply. For instance, bread consumers pay only 50% of the market price and per capita consumption of bread in Iran is 160 kilograms, which is almost six times of the global average (The Statistical Center of Iran 2017). Given the driving factors of water crisis, nowadays the water resources management is an important issue at the national level (Madani 2014). Management of water resource systems may address different and conflicting objectives for stakeholders. Therefore, it is essential to apply a holistic approach for planning, management and decision making in water system to avoid policy resistance (Sterman 2001) and unsustainability in the socioeconomic or environmental systems (Mirchi 2013). There are dynamic feedback relationships among different factors in the supply and demand sides of the water systems (Kotir *et al*. 2016). Furthermore, changes in water resources have dynamic behaviors and affected by many socio-economic and climatic factors over time (Sterman 2012). In other words, population growth, climate change, changes in harvesting rate from ground and surface water are factors that affect the water system of a region over time with interaction. Also, the use of water in one sector also affects other sectors, and the agents in the water system are contiguous. To avoid an undesirable result, various policies in water resources management in different sectors, including agriculture, must consider all complex interactions as a system. Regarding the complicated interactions and feedback between different factors, to understand the consequences of a change in the water system, a comprehensive and interactions-based approaches is needed. System Dynamic (SD) is a strong and effective approach to examine the behavior of complex systems over time (Ford and Ford, 1999). SD considers the interactions among different elements, feedbacks, stock-flow relationships, and time delays for simulating the behavior of the system and policy analysis (Draper 1993, Forrester 1994, Frank 2000, Sterman 2001).

It is useful for assessing the behavior of complex systems in the environment (Ford & Ford 1999, Mulligan & Wainwright 2004) and water system problems (Madani & Mariño 2009, Rehan *et al*. 2011, Wang *et al*. 2011, Atherton 2013, Balali & Viaggi 2015). Feedback loops and stock and flow make SD different from other approaches to analyzing complex system such as water system (Forrester 1997). There is a large body in the literature applying SD modeling to evaluate the effect of changes in some variables like water demand (Forrester & Senge 1996), population control, water transfer as well as climate change on water availability (Sušnik *et al*. 2012, Dawadi & Ahmad 2013, Hassanzadeh *et al*. 2014, Gain & Giupponi 2015, Balali & Viaggi 2015, Gohari *et al*. 2017). Recently, Kotir *et al*. (2016) used SD modeling to examine the long-term dynamic behavior of the river basin in Ghana and examined the effects of different policies on water resource and agricultural development. Gohari *et al*. (2017) also applied SD modeling to discover the effects of climate change at the river basin in Iran. Although most of the above-mentioned studies have focused on the interaction between elements and feedback loops in the water system, a few of them have been designed to analyze various water indicators, for instance, sustainability index (Gohari *et al*. 2017). In the real world, on one hand the limited water supply could drive management options to reduce the demand, on the other hands the increase in water demand could also lead to diverse water supply options, indicating the complicated and inter-related nature of the water system. However, the interaction between water supply and demand is not well developed in the existing models (Zhuang 2014). These interactions can be considered through indicators of demand and supply such as water resource sustainability index.

The water resource sustainability index is defined as the ratio of water supply and demand (Madani & Mariño 2009) and summarizes the performance of alternative scenarios and policies (Loucks 1997). By decreasing the water resource sustainability index, as a result of climate variability and population growth, both demand and supply management options can be considered. The demand management options in the residential sector (domestic water demand) and in the agriculture sector (agricultural water demand) can be implemented by reducing per capita water demand and increasing irrigation efficiency, respectively.

Given the growing population and demand for food, as well as the reduction of water supply by precipitation, for exploring the water resource sustainable index in the Kowsar dam basin in southwestern Iran, this paper applied

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an integrated SD simulation model. Kowsar dam, located in Zohre River basin is in the west of Gachsaran County in Kohgiluyeh and Boyerahmad Province, southwestern Iran (Fig. 1). The dam height is 144 m and the river width ranges from 6 to 8 m. The conservation storage volumes for the Kowsar reservoir is 580 mcm and every year over 300 mcm is supplied for various usages. The water stored in Kowsar dam has declined in recent years (Regional Water Organization of Kohgiluyeh and Boyerahmad Province 2017). Because one of the most important goals of the Kowsar dam construction is the supply of drinking water in the southern provinces of Iran and agricultural development in these areas, meeting the growing water demand in this basin is becoming a concern among policymakers. Therefore, there is a crucial need to make an accurate simulation about the water availability to help policymakers adopting appropriate policies as well as achieving sustainable water management.

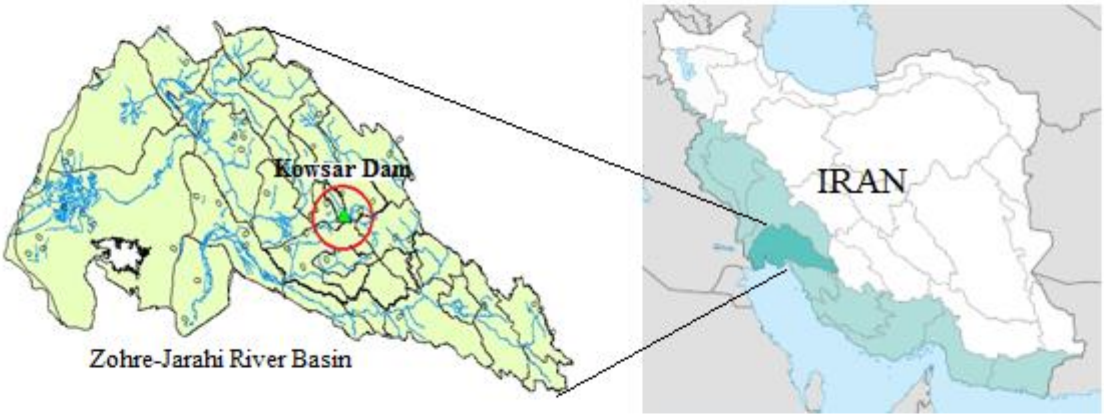

Fig. 1. Zoher-Jarahi River Basin and Kowsar Dam.

Put it simply, the present study aims to evaluate the impact of climate variability (change in precipitation rate and temperature), population growth and demand-side management policy (controlling water demand in agriculture and domestic sectors) on resource sustainability. To achieve this goal, this study presents an integrated system dynamics simulation model for Kowsar dam basin. The model includes water supply and water demand subsystems. The major contribution of the study to the literature is the use of water resources sustainability index to assess different scenarios in the water system.

This paper is organized as follows. The SD model features are presented in the next section. Then, the applied data are described. The simulation results of the model are presented in Section 3 and the conclusions and policy implications are provided in Section 4.

MATERIALS AND METHODS

System Dynamics Modelling

SD modeling is an iterative and feedback process to reach new understanding of how the problem arises and then design high leverage policies for improvement (Sterman 2001, Davies & Simonovic 2011). The first step in SD modeling is to be specific about the dynamic problem and problem articulation (Ford & Ford 1999). This step includes model formulation, model testing, and analysis of the resulting outputs and alternative inputs are related to the first step (Zhuang 2014).

The aim of model formulation is representing the structure of the problem and formulating a SD simulation model of the causal theory (Sterman 2001, Zhuang 2014). There are several diagram tools to capture the structure of the system, including causal loop diagram (CLD) and stock and flow diagram. CLDs consist of variables connected by arrows for representing the feedback structure of the system (Sterman 2001). In spite of the fact that stock and flow and feedback are the two central concepts of system dynamic theory, CLDs are not able to capture the stock and flow structure of a system (Ford & Ford 1999, Sterman 2001). This is an important reason for using stock and flow diagram to represent the structure of a system with more detailed information that is shown in a CLD. In general, the stock variable is an accumulator variable (Zhuang 2014). Thus, a stock with a single inflow and single outflow can be mathematically formulated as:

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$$stock(t)=\int_{t_0}^{t}[Inflow(s)-outflow(s)]ds+stock(t_0) \quad (1)$$

Model testing begins as the first equation is written and it is a critical step in SD modeling (Sterman 2001). Tests to rely on SD model can be divided into two groups, structure tests and behavior tests (Forrester 1997). Structure tests compare the structure of the SD model with the available knowledge about the real system presented in historical data. Behavior test is to run the model and compare the results to the reference mode (Historical or observed data). When the simulation results match the reference mode, you have reached a major milestone in the modeling process (Ford & Ford 1999). Following Steel and Torrie (1980) and Kotir *et al*. (2016), maximum relative errors (M) and coefficient of determination (R^2) were applied to evaluate the performance of the model. M indicates the maximum possible divergence between the observed and simulated data (Qin *et al*. 2011), the lower values of this variable indicates that the model satisfactory fits the historical values. R^2 describes the proportion of the variance in measured data explained by the model (Moriasi *et al*. 2007, Wu *et al*. 2013, Kotir *et al*. 2016).

$$M=\frac{\sum(Y_i-\hat{Y}_i)}{\sum Y_i} \quad (2)$$

$$R^2=1-\frac{\sum(Y_i-\hat{Y}_i)^2}{\sum(Y_i-\bar{Y}_i)^2} \quad (3)$$

Where Y_i and $\hat{Y}_i$ are the observed and simulated values of tested variable and $\bar{Y}$ is the average of observed values of variable. After the validation of the model, we can use this model to evaluate the impact of different scenarios designed to solve the problem (Zhuang 2014).

Kowsar dam basin and water system

As mentioned before, in this study, the water system consists of two subsystems namely water demand and water supply. The water demand subsystem is depicted in Fig. 2. This subsystem represents water demand within the basin. Kowsar dam provides water for residential, industrial, agricultural and environmental usages. Generally, population is the main driving factor in water demand. Population influence the domestic water demand directly and other sources of water demands affect indirectly (Davies & Simonovic 2011). There are some towns and villages on the Kowsar dam watersheds and Gachsaran is the largest and the most populated city in this area. The dam provides water to the Persian Gulf littoral cities and ports for nearly 20 years. The total population of the selected area was 1.76 million in 2016 (The Statistical Center of Iran 2017), with most being in urban areas. Population sub-model represents the population of the case study including one stock "Population" which is increasing by population growth rate. The population at time t is mathematically represented by equation 4 as follows:

$$Population(t)=Population(0)-\int_{t0}^{t}(Population\ growth\ rate)dt \quad (4)$$

Water demands include water for agriculture (Irrigation), residential (Domestic), industrial and environmental purposes. Following Davies and Simonovic (2011), domestic water demand (DWD) is expressed as a function of population and per capita water demand (PW) in the Kowsar dam basin model. Agricultural water demand (AWD) is assumed to be as an exogenous variable and environmental water demand (EWD) is defined as a look up function of time. For calculating industrial water demand (IWD), per capita industry water use (PIW) is applied (Balali & Viaggi 2015), in which industrial water demand equals population multiplier per capita industry water use. Total water withdrawal from the basin was estimated as the sum of agricultural, domestic, environmental and industrial water demands as follows:

$$\text{Water Demand in Basin}_t=\text{DWD}_t+\text{AWD}_t+\text{IWD}_t+\text{EWD}_t \quad (5)$$

$$\text{DWD}_t=\text{population}_t\times\text{PW}$$
$$\text{IWD}_t=\text{population}_t\times\text{PIW} \quad (6)$$

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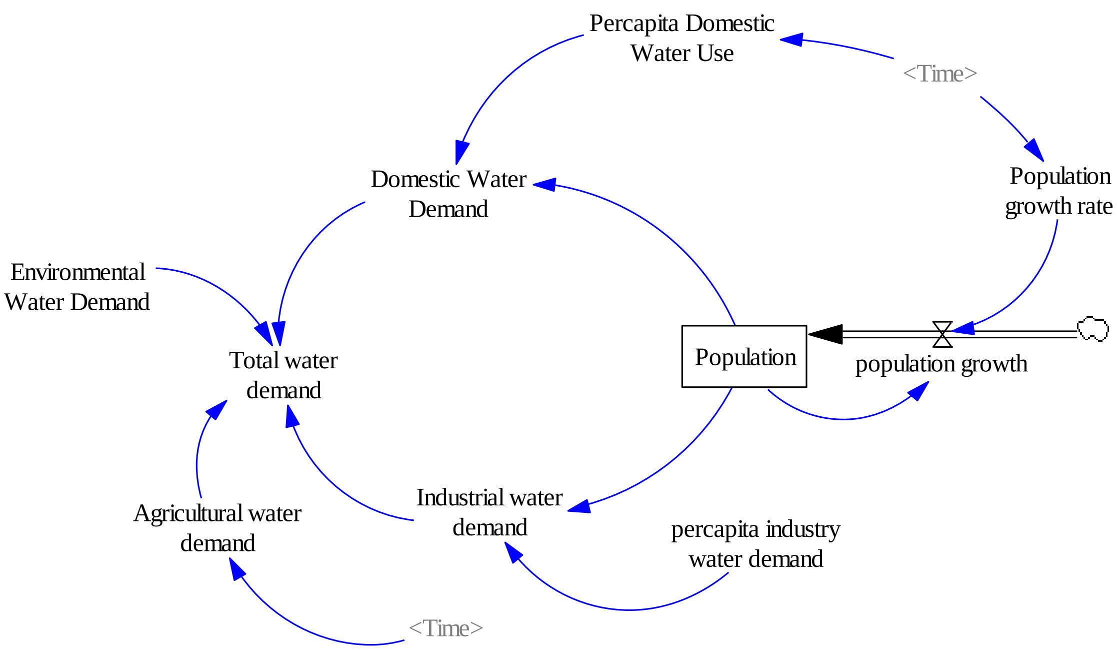

Fig. 2. Population stock and flow diagram.

The water supply subsystem focuses on surface water resources (Fig. 3). This is because of the fact that there is not enough data available on groundwater resources in the region. The amount of precipitation, surface water inflows, and outflows, spillway, and evaporation determine the amount of water stored in the dam. The average annual surface water inflow is estimated to be 310 mcm. Evaporation, the volume of water evaporated from the reservoir surface at each time step, is calculated by multiplying evaporation rate by the reservoir's surface area. The surface water area will decline with a decrease in the volume of water in the dam. At each time step, the reservoir surface area is taken from a water storage in dam which is represented as a LOOKUP Table (Equation 11). Lookup Tables are typically used in SD modeling to represent nonlinear relationships between two variables. A table function can be defined as a list of numbers whereby input values to a function are positioned relative to the x axis and output values are read from the y axis (Ford & Ford 1999, Vensim Reference Manual 2011). For this, the volume of water storage in the dam is used as an input for the lookup table and the surface area is used as an output. Annual evaporation and runoff in water supply and demand subsystem is measured into surface area multiplier in evaporation and precipitation rate (EV and PR) (Equations 9 and 10). The average annual precipitation for this region is 449 mm and average annual temperature is 14.9 °C and evaporation rate is considered as a function of temperature.

$$\text{water storage}(t) = \text{water storage}(0) + \int (\text{total water inflow} - \text{total water outflow})dt \quad \textbf{(7)}$$

$$\text{totalwater INFLOW}_t = \text{surface INFLOW}_t + \text{runoff}_t$$
$$\text{total water outflow}_t = \text{spillway}_t + \text{evporation}_t + \text{outflow}_t \quad \textbf{(8)}$$

$$\text{evporation}_t = \text{surface area}_t \times \text{EV} \quad \textbf{(9)}$$

$$\text{runoff}_t = \text{surface area}_t \times \text{PR} \quad \textbf{(10)}$$

$$\text{surface area} = \text{LOOKUPFunction}(\text{waterstorage in DAM}) \quad \textbf{(11)}$$

$$\text{EV} = \text{temprature} \times \text{effect of temprature on EV} \quad \textbf{(12)}$$

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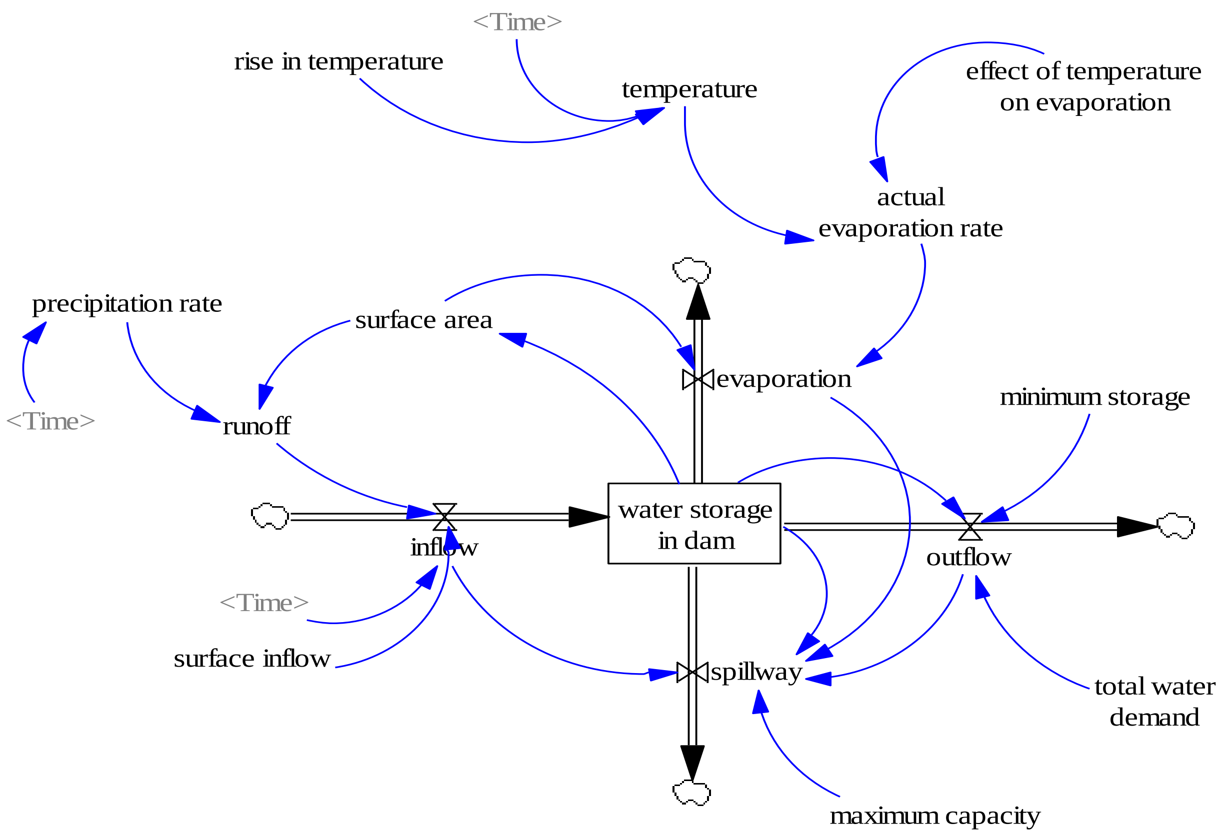

Fig. 3. Water supply stock and flow diagram.

This study applies a water resources sustainability index to evaluate and compare different scenarios with respect to their sustainability. Sustainability of water resources is essential to ensure that available water can be used by both present and future generations. To ensure sustainability, a comprehensive knowledge of the water system is essential. The water sustainability index is a useful tool to determine the state of a water system in different conditions. It is also a helpful tool for recognizing the factors affecting these conditions in order to design sustainable water management policies (Juwana 2012).

Sustainability Index

The sustainability index (SI) is a measure of a system's adaptive capacity to reduce its vulnerability (Loucks 1997). To evaluate and compare the water management policies Loucks (1997) suggested SI formulated by Eq. (13):

$$SI = \left[REI \times (1 - VUL) * (1 - MAX\ DEF)\right]^{1/3} \quad \textbf{(13)}$$

where SI is sustainability index, REI, VUL and MAX DEF are reliability index, vulnerability index and maximum deficit, respectively. Water demand reliability is the probability that the available water supply meets the water demand during the period of simulation (Hashimoto *et al*. 1982, Klemeš *et al*. 1981). For each time period deficits (D) are positive when the water demand is more than water supplied, i.e.:

$$D = \begin{cases} WD - WS & \text{if} \quad WD > WS \\ 0 & \text{otherwise} \end{cases} \quad \textbf{(14)}$$

The reliability REI is calculated by dividing the number of times D = 0 by the length of the simulation period (McMahon *et al*. 2006):

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$$REI = \frac{number\,of\;time\,D = 0}{N} \tag{15}$$

The vulnerability index is the likely value of deficits if they occur (Hashimoto *et al*. 1982). Vulnerability is calculated by dividing the average annual deficit by the average annual water demand in deficit period (Gohari *et al*. 2017, Sandoval-Solis *et al*. 2011):

$$VUL = \frac{(\sum D)\,/\,number\,of\;times\,D > 0\,occurred}{Water\;Demand} \tag{16}$$

The maximum deficit, if deficits occur, is calculated by dividing the maximum annual deficit by the annual water demand (Moy *et al*. 1986):

$$Max\,Def = \frac{\max(D_{Annual})}{water\;demand} \tag{17}$$

Table 1 shows the initial values of the stock and some key exogenous variables used for the SD model.

Table 1. The stock and exogenous variables of water system.

Variable type	Variable name	Initial value	Unit
Stock Variable	Population	1.76	Million person
	Water storage	477.16	mcm
Exogenous variable	per capita industry water use	2.13	m^3
	per capita domestic water use	0.62	m^3
	agricultural water demand	91.32	mcm
	precipitation rate	449	mm
	temperature	14.9	c

Scenarios

To achieve the objectives of this study, eight scenarios are defined based on different levels of precipitation, temperature, and population growth rate. Based on the study conducted by the Research Center of Iranian Parliament (2017), three possible changes may occur by the end of the simulation period. These include optimistic weather conditions (27% change in precipitation and 0.4 °C increase in temperature), pessimistic weather conditions (-21.5% change in precipitation, 1c increase in temperature) and normal weather conditions (-6% change in precipitation and 1c increase in temperature). On the other hands, there are three estimates for Iranian population growth, i.e., 1.59%, 1.87% and 1.38% during 2016-2020, 2020-2027 and 2027-2030, respectively (the Statistical Center of Iran 2017).

The Iranian Statistics Center also reports that average per capita water demand in Kohgiluyeh and Boyerahmad is higher than its country average. Thus, reduction in average per capita water demand is defined as another scenario along with the decline in agricultural water demand. A short description of the scenarios are presented in Table 2.

At first, the base line scenario runs over the simulated period in which it is assumed that current environmental conditions within the basin would remain the same without any changes. Then, the behavior of the system is evaluated under the above-mentioned scenarios.

Vensim Professional 5 (Ventana Systems 2009), one of several software packages available for SD modeling, is applied to develop and run the Kowsar dam basin model.

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Table 2. Description of different scenarios.

Scenarios	Input to the model	
Baseline model	Current environmental conditions within the basin would remain the same without any change (Precipitation rate is 449 mm/year, Average temperature is 14.9 °C, population growth rate is 1.59% and average water demand per capita is 62.05 m^3/year).	
Almost Optimistic conditions	Precipitation increase rate	27%
	average temperature increase by 2030	0.4 °C
	population growth rate over	
	2016-2020	1.59%
	2021-2027	1.87%
	2027-2030	1.38%
Pessimistic Conditions	Precipitation decrease rate	21.5%
	average temperature increase by 2030	1 °C
	population growth rate over	
	2016-2020	1.59%
	2021-2027	1.87%
	2027-2030	1.38%
Almost Normal Conditions	Precipitation decrease rate	6%
	average temperature increase by 2030	0.7 °C
	population growth rate over	
	2016-2020	1.59%
	2021-2027	1.87%
	2027-2030	1.38%
Optimistic Conditions	Optimistic Weather Condition along with 10% reduction in average water demand per capita	
Almost Pessimistic Conditions	Pessimistic Weather Condition along with 10% reduction in agricultural water consumption	
Normal Conditions	Normal Weather Conditions along with 10% reduction in agricultural water demand and average water demand per capita (Combined two previous water demand side policies at normal weather conditions)	
Absolutely Optimistic conditions	Optimistic Weather Conditions along with 10% reduction in agricultural water demand and average water demand per capita	
Nearby baseline conditions	Current Environmental Conditions along with 10% reduction in agricultural water demand and average water demand per capita	

RESULTS AND DISCUSSION

The performance of the model is discussed by comparing model outputs for the selected variables to the corresponding historical data. The key variable that demonstrates the performance of the water system is water storage in the *Kowsar* dam. In general, as shown in Fig. 4, the model performed well in comparison to the historical data.

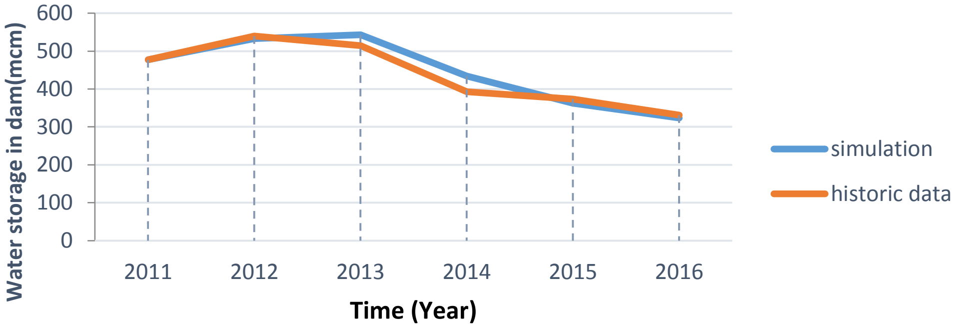

Fig. 4. The observed and simulated values of water storage.

The simulated results follow the same trend as the observed date, indicating that the model is well calibrated. The statistical values for M and R^2 show that the model satisfactorily fits the historical values. Predictions for water storage have low values of M (less than 10%) and the value of R^2 is calculated around 0.92 (Table 3).

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Table 3. Statistical parameters of the model tests.

Variable	M (%)						R^2
Year	2012	2013	2014	2015	2016	2011-2016	2011-2016
Water Storage	1.24	-5.53	-10.51	3.02	2.12	-1.70	0.92

After testing the reliability of the model, the SD model is implemented under different scenarios. The behavior of the system is then simulated over time to assess the availability of water resources and sustainability index. The behavior of the selected variables of the system including water storage in the dam and total demand under the baseline scenario are shown in Fig. 5.

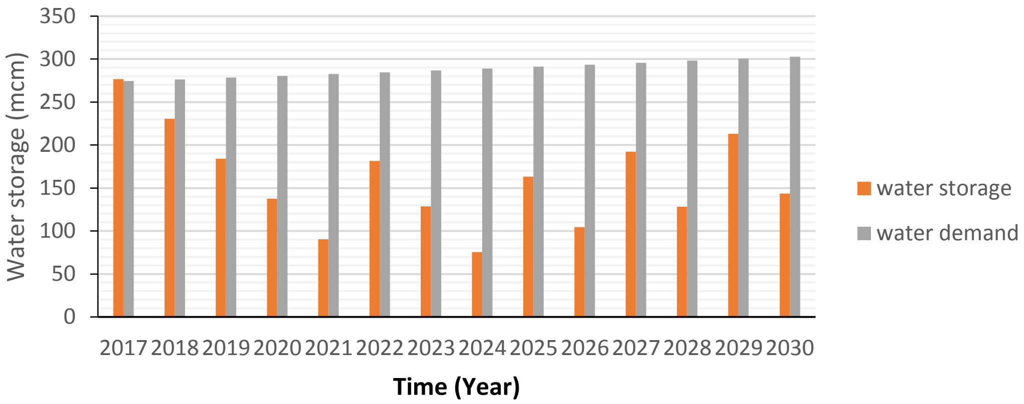

Fig. 5. Water storage and demand (mcm) in the basin during simulation period.

The results indicate that the water storage volume is decreasing in some years and is increasing in others. However, given the beginning and end of the simulation period, it shows that the amount of water storage decreases. However, the total water demand in the basin is increasing due to population growth. In order to examine this fact in more details, noteworthy, the volume of water stored in the dam decreases from 230.40 mcm in 2018 to 143.68 mcm at the end of the simulation period. Also, total demand in basin increases during the simulation period as a result of population growth. Therefore, it is expected that the gap between supply and demand for water increases continuously and the water system becomes more vulnerable in the future.

Water storage increases by the surface water inflow, precipitation, and runoff, while decreases by evaporation and the surface water withdrawals. However, the surface water withdrawal is determined by surface water level. It means that if the volume of water storage falls below minimum storage, water withdrawal decreases and the volume of water in the dam reaches the ascending trend. The upraised water storage will consequently induce an elevation in the surface water area and evaporation, consequently the volume of water will drop again. It is expected that if the current trend continues, the amount of stored water will not meet future water demand. The simulated values for the main variables in each scenario are presented in Table 4. Simulation results indicate how changes in climatic variables and population growth can affect the whole system. The results of the scenarios demonstrate the effect of climate variables and population growth on the imbalance between water availability and demand in the water system over time.

As shown in Table 4, under the almost optimistic scenario, water storage in the dam decreases by 38.8% on average during 2018-2030 and reaches about 101 mcm at the end of the simulation period. An increase in the population in the basin increases the total water demand by almost 6.02 %. Also, the upward trend of precipitation leads to an increase in surface water flow. Although under this scenario, the inflow increases, while maintaining a larger water harvest to meet domestic water demand and increasing evaporation, the reservoir level of the dam will be lower than the baseline scenario.

By decreasing precipitation and increasing temperature and continuity of drought at the basin (pessimistic scenario), surface water inflow decreases during the simulation period and the water storage in dam follows the trend of precipitation. On the other hand, increasing temperature raises the evaporation of water, which is related to the surface area of the water storage in the dam. By contrast, population growth directly affects water demand and increases withdrawal of water storage. In fact, water storage in the dam decreases by more than 47% by the

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end of the study period while the population and water demand increase to 2.4 million and 304.88 mcm, respectively.

Table 4. Simulated values of selected variables under different scenarios.

Year	baseline	Almost Optimistic	Pessimistic	Almost Normal	Optimistic	Almost Pessimistic	Normal	Absolutely Optimistic	Nearby baseline
Water storage (mcm)									
2018	230.4	229.83	228.59	229.17	252.17	246.11	269.73	270.79	271.02
2020	137.52	135.21	130.16	132.51	180.48	163.93	211.19	215.60	216.57
2025	163.33	146.22	128.16	135.60	108.19	199.55	169.10	189.68	197.3
2030	143.68	100.73	71.87	79.98	119.61	169.95	209.95	108.97	133.56
Change (%)	**-38.50**	**-38.80**	**-47.19**	**-43.64**	**-41.39**	**-40.32**	**-41.26**	**-43.10**	**-44.08**
Water demand									
2018	276.37	276.37	276.37	276.37	264.14	267.24	255.01	255.01	255.01
2020	280.44	280.44	280.44	280.44	277.82	271.31	258.68	258.68	258.68
2025	291.20	293.18	293.18	293.18	279.32	284.05	270.19	270.19	268.41
2030	302.85	304.88	304.88	304.88	289.89	295.75	280.76	280.76	278.93
Change (%)	**5.43**	**6.02**	**6.02**	**6.02**	**5.69**	**6.23**	**5.90**	**5.90**	**5.32**
Water inflow (mcm)									
2018	258.35	258.50	258.21	258.31	258.69	258.35	258.63	258.84	258.84
2020	257.82	258.07	257.58	257.74	258.33	257.74	258.16	258.54	258.54
2025	257.95	258.46	257.31	257.68	258.24	257.64	257.65	258.74	258.74
2030	257.85	258.52	256.95	257.45	258.45	257.22	257.99	258.55	258.55
Change (%)	**-0.19**	**-0.03**	**-0.35**	**-0.24**	**-0.08**	**-0.36**	**-0.32**	**-0.12**	**-0.30**
Evaporation (mcm)									
2018	28.19	29.01	30.23	29.62	30.37	31.31	32.07	30.96	30.51
2020	24.40	25.80	27.53	26.81	27.63	28.95	30.20	28.29	27.49
2025	25.35	28.01	29.74	28.82	26.43	33.14	30.31	28.23	26.72
2030	24.62	27.11	30.51	28.96	27.81	34.77	34.08	25.85	24.25
Change (%)	**-12.29**	**-4.99**	**-0.15**	**-3.02**	**-7.96**	**-1.93**	**-6.66**	**-13.44**	**-17.93**
Population (million person)									
2018	1.971	1.971	1.971	1.971	1.971	1.971	1.971	1.971	1.971
2020	2.034	2.034	2.034	2.034	2.034	2.034	2.034	2.034	2.034
2025	2.202	2.233	2.233	2.233	2.233	2.233	2.233	2.233	2.202
2030	2.384	2.415	2.415	2.415	2.415	2.415	2.415	2.415	2.384
Change (%)	**11.86**	**13.16**	**13.16**	**13.16**	**13.16**	**13.16**	**13.16**	**13.16**	**11.86**

Comparing the results of the Table 3 in different scenarios, it can be concluded that under almost optimistic conditions we expect that sustainability in water system to be higher than pessimistic ones. The findings also reveal that, under the almost normal condition of precipitation in the study area (the fourth scenario), the water storage in the dam will improve during the simulation period compared with the almost pessimistic condition. It is clear that, with increasing precipitation, surface water inflow will increase and the water system will be in a better situation in terms of sustainability.If the demand management options are implem ented in optimistic condition, the average annual growth of water demand at the basin will decrease from 6.02% to 5.69% in comparison to the almost optimistic condition. However, the water storage in dam increases to 119.61 mcm at the

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end of simulation period. Therefore, lower per capita water demand accompanied by a constant population will reduce the water withdrawals of *Kowsar* dam and may be an effective option to improve the sustainability of water resources. The negative effects of pessimistic condition on surface water inflow to the basin leads to lower levels of water resources availability. In comparison to the pessimistic conditions, a 10% decline in agricultural water demand improves the surface water level by the end of study period. The water storage in dam, under almost pessimistic conditions, will be close to 170 mcm and water demand is expected to be 295 mcm at the end of the simulation period. Therefore, controlling agricultural water demand using water conservation options such as increasing irrigation efficiency or changing crop pattern can help achieve a better balance between supply and demand of water and improve the water sustainability index even under climate changes. A reduction in agricultural water demand along with per capita water demand at the basin under normal and optimistic condition (seventh and eighth scenarios) can increase the surface water availability and decrease water shortage in the study area. For the similar reason, the water demand at the end of the simulation period will be 280.76 mcm, which is lower than the corresponding value in the other scenarios. Agriculture is the largest water user in Iran, where irrigation efficiency is low, and accounts for about 90% of water use (Madani and Mariño 2009). Therefore, water demand management policies in this sector may have a significant impact on sustainable water management. If current environmental conditions within the basin would remain the same without any changes (Baseline), demand management policies, such as controlling domestic and agricultural water demand (ninth scenario), can increase the sustainability of water resources. By way of explanation, water demand is expected to be 255 mcm in 2018 and 279 mcm at the end of the simulation period. Increasing water storage in dam is expected to increase the ability to meet the demand for water in the basin in this condition. Therefore, it can be concluded that water demand control policy has a positive effect on sustainable water resources management. The behavior of water storage in the dam and total water demand under different scenarios are shown in Figs. 6-7. According to Fig. 7, water demand grows during the simulation period under different scenarios with a consistent pattern, while changes in the volume of water storage have an irregular trend. This behavior of the water storage is related to the structure of the system and how this variable is affected by variables such as evaporation, surface water area, and minimum storage. For instance, in some scenarios, such as the pessimistic scenario, the volume of water storage may reach the minimum volume faster than other scenarios. Therefore, water harvesting decreases and it is expected that in next years, the volume of water storage will be increasing. Generally, these upward trends in water demand along with the decreasing trend in available surface water resulted from change in precipitation rate and temperature, may lead to serious water deficit in the future, having a negative effect on agriculture as the main activity in the basin.

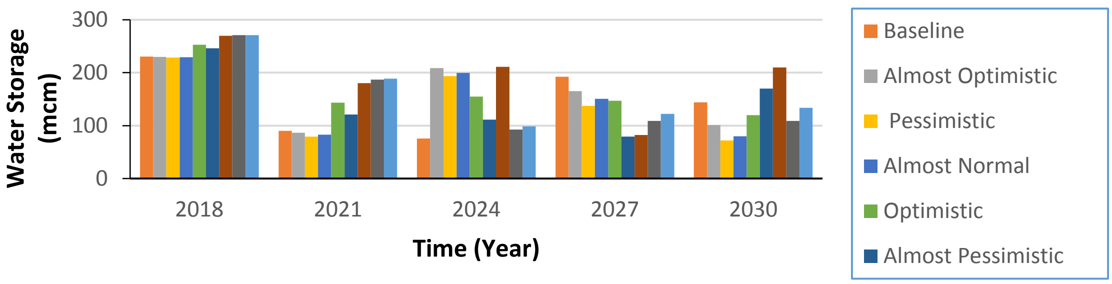

Fig. 6. Water storage (mcm) in the kowsar dam.

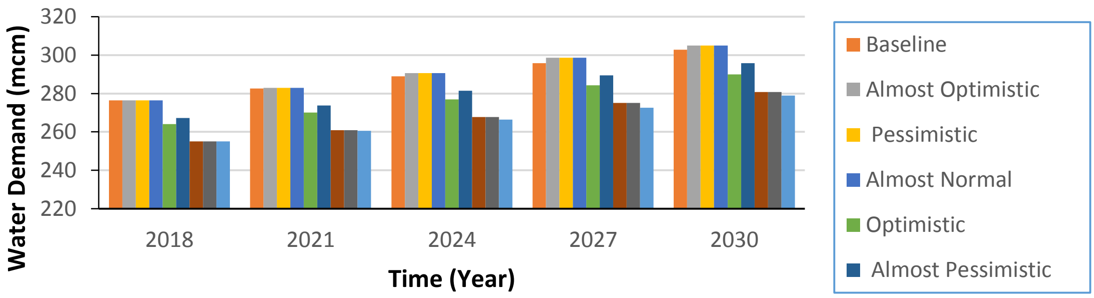

Fig. 7. Water demand (mcm) in the case study.

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The impact of climate variability and population growth on water resources in the *Kowsar* dam basin is assessed using four indices. Table 5 shows the values of the indices under different scenarios. Under pessimistic conditions, water supply decreases, while population, industrial and domestic water demand increase over time. Therefore, the reliability and sustainability indices for pessimistic conditions are lower than those of the baseline. According to Table 4, the sustainability index for pessimistic conditions decreases by about 20% in comparison to the baseline. However, with the assumption of almost optimistic conditions in the basin, the reliability and sustainability indices increase. Although the demand for water increases as a result of population growth, the surface water inflow and water resources availability are higher than baseline. The reliability and sustainability indices in almost optimistic conditions are 0.50 and 0.702, respectively. The results also revealed that the sustainability index for almost normal condition is higher than those of pessimistic condition but it is lower than the index for baseline and almost optimistic conditions. The water sustainability index for normal conditions is 0.601. As shown in Table 5, under optimistic conditions, the reliability and sustainability indices are higher than those for the baseline (0.714 and 0.798, respectively). In terms of water availability, although pessimistic conditions put the water system in the worse situation, the implementation of demand control policies likely help to meet the growing water demand. The sustainability index for *Kowsar* dam basin under almost pessimistic condition increases by 3.15% in comparison with the baseline. Also, a 10% reduction in per capita water demand and agriculture water demand in almost optimistic condition increases the sustainability water index to 0.852 and decreases vulnerability index to 0.105, compared to almost optimistic condition without any actions.
The results also show that the reliability and sustainability indices in nearby current conditions are 0.714 and 0.817, respectively. Therefore, the water demand control policies in current conditions can play significant role to supply sufficient water for increasing demand over time.
Maximum and minimum sustainability index for the water system belong to absolutely optimistic conditions and pessimistic conditions, respectively. This result confirms the negative impact of climate change on the sustainability of the water system (Gohari *et al*. 2017) and the positive impact of demand control options (Zhuang 2014). In general, controlling water demand leads to lowering the vulnerability and all other indices are improved compared to the baseline.

Table 5. Water indices under different scenarios.

	Reliability	Vulnerability	Max Deficit	Sustainability
Base line model	0.571	0.131	0.244	0.721
Almost Optimistic conditions	0.500	0.113	0.219	0.702
Pessimistic Conditions	0.357	0.173	0.368	0.572
Almost Normal Conditions	0.357	0.132	0.299	0.601
Optimistic conditions	0.714	0.123	0.188	0.798
Almost Pessimistic Conditions	0.643	0.136	0.258	0.744
Normal Conditions	0.714	0.087	0.191	0.808
Absolutely Optimistic conditions	0.786	0.105	0.119	0.852
Nearby current conditions	0.714	0.073	0.175	0.817

CONCLUSION

This study applies system dynamics approach to analyze the impacts of climate variability, population growth and water demand management options on supply and demand of water in *Kowsar* dam basin located in west southern Iran. After defining the boundaries of system and designing a stock and flow diagram, the effects of climate variability and population growth along with controlling water demand on sustainability was examined under eight scenarios: a baseline scenario that represents the current condition in the basin and the alternative scenarios. The alternative scenarios represent climate change, population growth, and change in average water demand per capita during 2018-2030. Based on the findings, under base line scenario, population growth contributes to 5.43% increase in demand for water and freshwater withdrawal of the dam during the simulation period. Under base line scenario, the water sustainability index is 0.721, indicating that the water supply at the basin will likely be unsustainable and total water demand is more than water supply and the maximum deficit index is more than zero in some years. Under the pessimistic conditions, the sustainability index is even lower (about 20%) than the baseline behavior. The lower precipitation causing from climate change, decreases the water supply. Moreover, the growth in population affects the water demand. It cannot be denied that the water system is vulnerable (vulnerability index in pessimistic condition is higher than the other conditions) due to an imbalanced supply and demand, caused by changing climatic conditions and increasing population. In other words, both of the supply

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and demand side of the water system is threatening since a growing water demand is accompanied by a possible drop in water supply caused by climate changes. Therefore, to meet the water demand in the near future with the population growth and climate changes, demand management policies are necessary (Dawadi & Ahmad 2013).
The highest sustainability index (the lowest vulnerability index) belongs to optimistic climatic conditions along with 10% reduction in per capita domestic water demand and agricultural water demand. However, even under these scenario water shortage maters. Again this fact points out urgent need of taking actions in water demand side. Given the possible increasing water shortage, water management policies should focus on demand side of water use to address the problem of water resource shortage. According to the results, a reduction in per capita water demand can play a significant role in decreasing vulnerability index and elevating the sustainability index. However, there is a large room in agriculture uses where the water use efficiency is much lower than the corresponding figures in the world. It is worth noting that drinking water is supplied by public sector and the price paid by the consumer's accounts for a slight part of the water costs. This may indicate that even in drinking part of water demand there is a considerable room for water demand management. As far as the agricultural use of water is considered, the lower water use efficiency is controversial. In Iran, resource constraints, in particular, water has always been a critical issue in agricultural production. On the other hands, the average irrigation efficiency is less than 35%, and only 5% of the farmed area is under modern irrigation system (Madani 2014). Inefficient agriculture irrigation could reduce production in this sector and subsequently reduce farm income, the immigration of farmers to urban areas to provide better living conditions. Under the circumstances that the world as a whole is facing water crises, many people have little information about how they can preserve water resources. To serve this purpose, the government should provide a context in which people learn to control their daily water consumption. It doesn't mean that we just focus on domestic water demand. Indeed, it argues that we can conserve water resources in agricultural sector with conservation policies.
Based on the data and the focus of the study, some of the variables were investigated while it may raise some questions that deserve to be recommended for future empirical works. For instance, a decrease in water supply may stimulate immigration from rural and agricultural-dominated areas to urban regions which is accompanied with some social-economic issues, needing to be examined. In addition, as a strategy to coping with the reduced water supply the agricultural growers may change their cropping pattern. Therefore, developing a more flexible system and investigating the possible effects on the cropping pattern is recommended.

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