BAE
Bio-based and Applied Economics

AIEAA
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Citation: G. Layani, M. Bakhshoodeh, M. Zibaei, D. Viaggi (2021). Sustainable water resources management under population growth and agricultural development in the Kheirabad river basin, Iran. *Bio-based and Applied Economics* 10(4): 305-323. doi: 10.36253/bae-10465

Received: February 15, 2021
Accepted: October 14, 2021
Published: March 31, 2022

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Fabio Gaetano Santeramo.

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Sustainable water resources management under population growth and agricultural development in the Kheirabad river basin, Iran

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Abstract. In this study, an integrated system dynamics model was developed for scenario analysis in sub-sectors of the *Kheirabad River Basin* in southwestern Iran where managing water resources is seriously challenging due to population growth and periodic drought. Afterward, the variability of water demand and supply under baseline scenario and different water demand management policies, including water conservation and water pricing, was evaluated. Findings illustrated that with increasing population and cropland area if no further demand management policies were implemented, the total water demand and withdrawal of water resources increase by more than 0.75% annually. The annual surface water availability during 2018-2030 is expected to decrease by around -1.23%. Under these circumstances, the sustainability index of the water resources system is equal to 0.703, indicating that the water system would not be able to meet the total water demand in the near future. However, the water resource sustainability index increases significantly by improving irrigation efficiency and changing crop patterns at the basin. Also, the reduction in per capita water demand and domestic water pricing under the competition structure would help to improve the sustainability index to 0.963 and 0.749, respectively.

Keywords: Sustainability Index, water system, system dynamics, agriculture, food security, Kheirabad River Basin.
JEL codes: Q2, Q25.

1. INTRODUCTION

Water is essential for people's daily life, agricultural irrigation, fish farming, and manufacturing (UNIDO, 2003). However, this vital resource is faced with several stresses in quantity and quality (Speelman & Veettil, 2013). Among the others, climate variability and increasing population growth have resulted in water scarcity in many countries especially in the arid regions (Hashemi *et al.*, 2019; Mulwa *et al.*, 2021). The water scarcity problem threatens nearly 80% of the world's population (Vallino *et al.*, 2020). Increasing

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water demand in various economic and social sectors exacerbates the problem of water scarcity (Donati *et al*., 2013) and can make the water system more vulnerable (Cai *et al*., 2018). Therefore, the most challenging issue in water resources system in the world is to achieve a balance between supply and demand (Kotir *et al*., 2016; Xiong *et al*., 2020).

The complexity of water systems is familiar to all those studying in the field because of fundamentally their large number of agents and interdependent subsystems (Madani and Mariño, 2009; Balali and Viaggi, 2015). In a water system, there are dynamic feedback relationships among different factors on the supply and demand sides (Kotir *et al*., 2016). Furthermore, the changes in water resource have a dynamics behavior as it is affected by many socio-economic and climatic factors over time (Sterman, 2001). In other words, population growth, climate change, agricultural development, changes in harvesting rate from ground and surface water are factors that affect the water system of a region over time with interaction (Brown *et al*., 2015). The use of water in one sector also affects other sectors, and the agents in the water system are contiguous. These interactions between different water users such as irrigation, drinking water, industrial production, and environmental facilities lead to complexity in the water resources system (Berger *et al*., 2007). These complexities in the water resources system cause policymakers to face policy resistance in managing water resources. Policy resistance occurs when policy actions trigger feedback from the environment that undermines the policy and at times even exacerbates the original problem. Policy resistance is common in complex systems characterized by many feedback loops with long delays between policy action and result (Sterman, 2001). Besides, implementing different policies to manage water resources, depending on the conflict of interest, may have different effects on different stakeholder groups (Darbandsari *et al*., 2020).

Addressing the complexities of water resources system, a holistic approach such as system dynamics (SD) can provide a sufficient water management framework based on conflict resolution approaches. System dynamics consider the interactions among different elements of different stockholders for simulating the behavior of the system and policy analysis (Frank, 2000). This helps decision-makers assess different management policies considering various aspects (e.g., economic, social, environmental, etc.) for simultaneously reducing conflicts and improving water resources conditions (Mirchi, 2013; Darbandsari *et al*., 2020). There are a large volume of published studies that have applied SD modeling to evaluate the effect of changes in some variables such as water demand, population control, water transfer as well as climate change on water availability (Gohari *et al*., 2017; Sun *et al*., 2017; Pluchinotta *et al*., 2018; Mahdavinia and Mokhtar, 2019; Keyhanpour *et al*., 2020). A great deal of previous research into water management has focused on mathematical programing, but they do not pay attention to the feedback processes in the water resources system (Donati *et al*., 2013; Archibald & Marshall, 2018; Zeng *et al*., 2019; Saif *et al*., 2020). Given the significant water consumption in the agricultural sector, these studies emphasize that local water management authorities, in addition to being aware of farmers' possible decisions to allocate farms, should also be able to provide an optimal cultivation pattern commensurate with the potential of each region (Donati *et al*., 2013).

Although good progress has been made in the SD modeling of water resources system in different studies, there are still limitations. Some important limitations of these studies are briefly as follows: (i) in general, less attention has been paid to theoretical foundations in modeling in the agricultural subsystem (Madani and Mariño, 2009; Gohari *et al*., 2017; Mahdavinia and Mokhtar, 2019); (ii) some studies (Kotir *et al*., 2016) considered the crop yields as a stock variable, which contradicts the definitions of the stock variable; (iii) in the population subsystem, few studies (Clifford Holmes *et al*., 2014; Goldani *et al*., 2011) have considered the behavior of consumers to change in water prices; (iv) 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 (Madani and Mariño, 2009; Gohari *et al*., 2017) have been designed to analyze various water indicators, for instance, sustainability index that is defined as the ratio of water supply and demand and summarizes the performance of alternative scenarios and policies (Loucks, 1997). It should be noted that the above points are important in studying the behavior of the water system at the basin. Compared to previous studies, to achieve a better result, we used a Nerlove (1956) partial adjustment framework to model the agricultural subsector and simulate cropland area and agricultural water demand. In more detail, farmers' decisions to develop the cropland area were considered in response to changes in crop prices in modeling. It can be an effective effort to more accurately simulate the agricultural water demand. Also in the population sub sector, consumers' responses to water price changes were taken into account. Policies such as taxes and subsidies can change the price of goods and correspondingly the quantity consumed. Thus, various indicators including sustainability (Loucks, 1997), reliability (McMahon *et al*., 2006), vulnerability (Hashimoto *et al*., 1982) and max deficit (Moy *et al*., 1986) indices, were considered to evaluate the effects of water resources management policies and to rank different policies base on their effects on water system behaviour.

Because of increasing complexity and integration of environmental, social, and economic functions, the early water resource models still need to be developed and appropriate policies should be adopted based on the socio-economic and environmental characteristics of basin. Accordingly, this paper develops an integrated SD simulation model for exploring the water resource sustainable index in the *Kheirabad river basin* in southwestern Iran where managing water resources is seriously challenging due to population growth and periodic drought. Put it simply, the present study aims to explore the water supply and demand dilemmas and calculate the water resource sustainability index at the basin.

This paper is organized as follows. The case study and 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 4 and the conclusions are provided in Section 5.

2. THE STUDY CONTEXT AND SCOPE

Iran is located in the mid-latitude belt of arid and semi-arid regions of the Earth. The arid and semi-arid regions cover more the 60% of the country Iran. The main source of water in Iran is precipitation in the form of 70% rainfall and 30% snow, which is estimated to be about 413 BCM (billion cubic meters). About 71.6% of the total rainfall (295 BCM) is directly evaporated. Considering 13 BCM of water entering from the borders (joint border rivers), the total amount of the country's renewable water resources (long-term averages for 1977 to 2018) is annually estimated to be 124 BCM, of which about 73 BCM go to surface runoff. Groundwater recharge is annually estimated to be about 51 BCM. Currently, total water consumption is approximately 88.5 BCM (Abbasi *et al*., 2015). Agricultural water consumption accounts for about 85% of total water resources in Iran and 90% of them may be allocated in surface irrigation systems with low efficiency and full water supply (Lalehzari *et al*., 2020). According to the latest figures, the average population growth rate in Iran during 1999-2000 was 1.755 percent and lowered to 1.246 percent in 2010-2017. However, in all these periods, Iran's population growth rate is above the global average (UNDATA, 2017). The annual water consumption in the urban areas of the country is about 5.4 BCM, of which 4.3 BCM is related to household consumption that implies to the per capita water consumption of 224 liters per person a day. As far as population growth is considered, the increasing demand is not limited to fresh water use for drinking purposes. The growing population is results in increasing demand for agricultural products as well, especially for some strategic food stuffs such as wheat that are provided at subsidized prices and the Iranian government insists on their domestic supply (The Statistical Center of Iran, 2018). Considering the driving factors of water crisis, the water resources management issue is a national priority and the most important issues among policymakers in Iran (Madani, 2014).

Kheirabad river basin is a part of the *Zohre river basin* in the *Kogiluyeh and Boyerahmad* province, southwestern Iran (Fig. 1). The average annual rainfall of the basin, where the rainfall regime is Mediterranean (with dry and wet season), varies from less than 200 mm to more than 800 mm The average annual temperature also varies from 12°c to 25°c. The water consumption of the *Kheirabad river basin* in the drinking, industrial and agricultural sectors is provided of surface and groundwater resources. This basin is rich in surface water, but the un-normalized utilization of soil and water resources and also the increasing water resources withdrawal have reduced the basin's water potential to meet increasing demands. Most of the surface water resource in the basin is provided by *Kowsar* reservoir dam located in *Zohre river basin* in the west of *Gachsaran* County. Rainfall is extremely seasonal; about 50% of which occurs in winter (concurrently with the smallest water demand), 23% in spring, 23% in autumn, and 4% in summer (concurrently with the greatest water demand). *Kheirabad river basin's* average annual precipitation is estimated to be 331 mm during 2012-2020 while evaporation amount is more than three times that. Not only the climate variability but also the population as an important factor affecting water demand, is continually increasing. While according to the report presented by the Regional Water Organization of Kogiluyeh and Boyerahmad province (2017), the average per capita domestic water consumption of this province is more than 220 liters per day, which is about 20 percent higher than the national average. The combination of these factors led to the water stored in *Kowsar* dam has declined in recent years. 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.

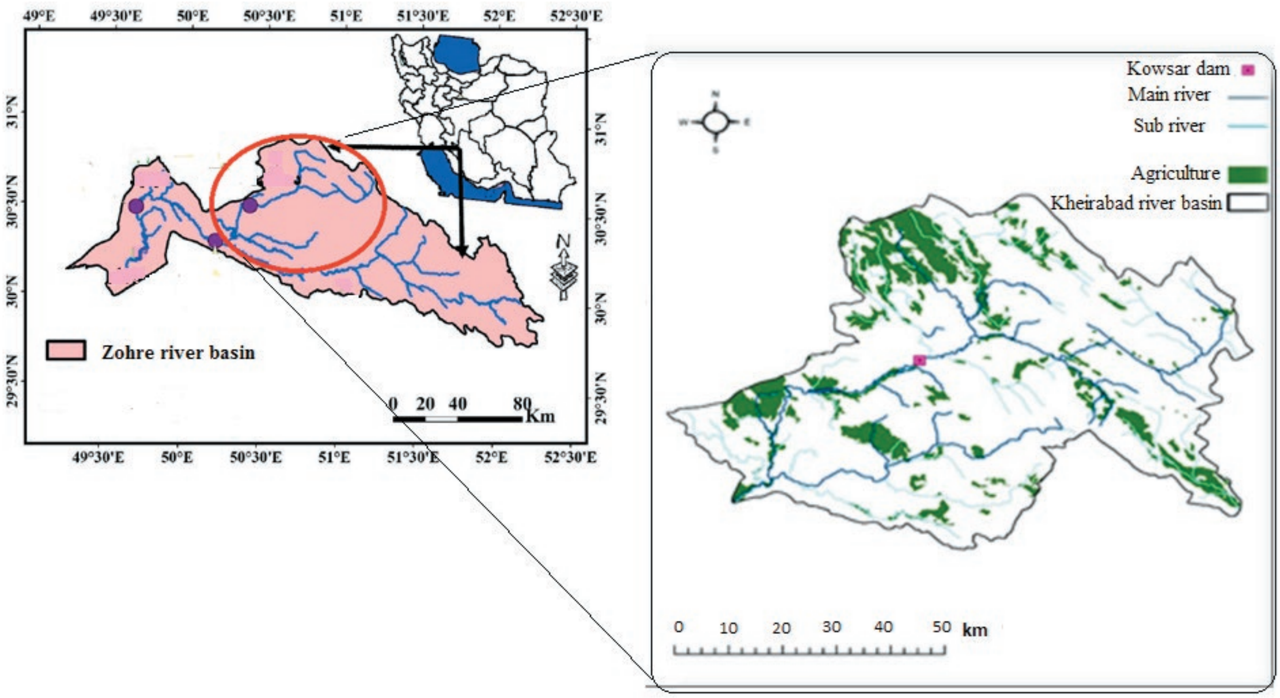

Figure 1. Kheirabad River Basin and Kowsar Dam.

3. SYSTEM DYNAMICS METHODOLOGY

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 (Davies and Simonovic, 2011). A four-step SD modeling process introduced by Sterman (2001) and Ford and Ford (1999) is used in this study: (1) Problem articulation; (2) Model formulation; (3) Model testing; (4) Scenario design and simulation. The first step in SD modeling is to be specific about the dynamic problem and problem articulation (Ford and Ford, 1999). This step includes defining the problem, identifying the key variables related to the problem, such as stocks, exogenous and endogenous variables, identifying the temporal and spatial scales to be considered (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 and 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). A stock with a single inflow and single outflow can be mathematically formulated as:

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

Where s is any time between t_0 and t. The stocks are the key variables in the model. They represent where accumulation or storage takes place in the system. Stocks tend to change less rapidly than other variables in the system, so they are responsible for the momentum or sluggishness in the system (Ford and Ford, 1999).

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[1] (Historical or observed data). When the simulation results match the reference mode, you have reached a major milestone in the modeling process (Ford and Ford, 1999). Following Kotir *et al.* (2016), mean relative errors (*MRE*) and coefficient of determination (R^2) were applied to evaluate the performance of the model. *MRE* indicates the mean possible divergence between the observed and simulated data (Qin *et al.*, 2011), the lower values of *MRE* indicates that the model satisfactory fits the historical values. R^2 describes the proportion of the variance in measured data explained by the model[2] (Kotir *et al.*, 2016).

$$MRE = \frac{1}{n}\sum\left(\frac{Y_i - \hat{Y}_i}{Y_i}\right)\times 100 \tag{2}$$

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

Where Y_i and $\hat{Y}_i$ are the observed and simulated values of tested or 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).

3.1. SD Modeling of Kheirabad River Basin

3.1.1. Water Supply Subsystem

The water supply subsystem includes feedback relationships between climate variables and water resources. This subsystem is constructed based on the surface and groundwater resources balance equation by taking in to consideration all inflows and outflows at the study area. This subsystem represents the measure of water resources available at the basin (Hjorth and Bagheri, 2006). Surface water resources available are controlled by various factors such as measure of precipitation, runoff, water inflow and outflow of surface water, evaporation, transpiration and infrastructural conditions (Hjorth and Bagheri, 2006; Gohari *et al.*, 2017). As shown in fig. 2, the water supply subsystem includes surface and groundwater resources. It is also worth mentioning that the surface and subsurface water inflows, return flow and precipitation are incoming inflows, and the surface and subsurface water outflows, evaporation, transpiration, water withdraw for kind of uses are outflows. Temperature and precipitation as climate variables affect the measure of available water. As a matter of fact, the increased precipitation can increase water availability. Strictly speaking, part of the precipitation is entered in to the water system as runoff (Eq. 4), taking into consideration of the runoff coefficient reported in the water balance studies of the study areas (Hjorth and Bagheri, 2006). Another part of the precipitation, joins to the groundwater resources considering the average percolation coefficient (Eq. 5). Also evaporation and transpiration was considered as a function of temperature in this study. Therefore, an increase of temperature in the future may affect the behavior of water resources system. Annual evaporation in water supply subsystem is measured into available surface water multiplier in evaporation rate (Eq. 6). At each time step, the evaporation rate is taken from temperature at the basin which is represented as a LOOKUP table[3].

$$\text{Runoff} = \text{Runoff rate} \times \text{Precipitation} \tag{4}$$

$$\text{Percolation} = \text{Percolation rate} \times \text{Precipitation} \tag{5}$$

$$\text{Evaporation} = \text{Evaporation rate} \times \text{Available surface water} \tag{6}$$

Also, the return flow in water system, according to Eq. 7, is as a percentage of the water consumption in different sectors that is added to the surface and groundwater resources. Total water withdrawal from the basin is measured into the sum of agricultural, domestic, environmental and industrial water demands. Following Davies and Simonovic (2011), domestic water demand is expressed as a function of population and per capita water demand in the *Kheirabad river basin* model. Agricultural water demand is expressed as a function of cropland area and water requirement for each crop. Environmental water demand is assumed to be as an exogenous variable. For calculating industrial water demand, per capita industry water use is applied (Balali and Viaggi, 2015), in which industrial water demand equals population multiplier per capita industry water use. The amount of surface water withdraw is equal to the part of total water demand that is supplied from surface water sources. According to the report presented by the Regional Water Organization of Kogiluyeh and Boyerahmad province (2017), 49% of agricultural water demand, 66% of urban water demand and 51% of indus-

1. A reference mode is a pattern of behavior over time

2. The values of R^2 range from 0 to 1, with values closer to 1 indicating that the model well simulates the system.

3. 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 and Ford 1999; Vensim Reference Manual 2011).

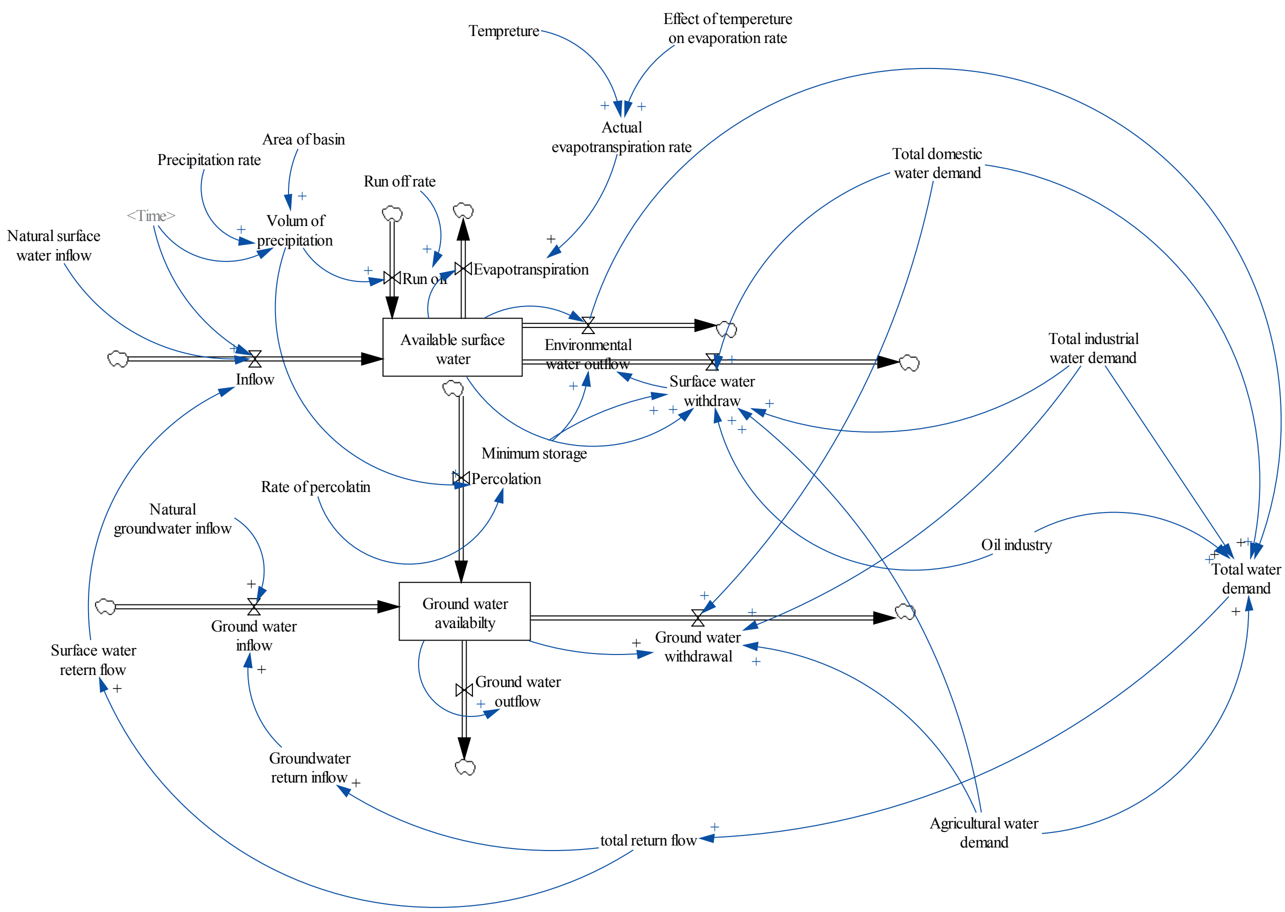

Figure 2. Water supply subsystem stock and flow diagram.

trial water demand at the basin are supplied from surface water sources.

$$\text{Return flow} = \text{Return rate} \times \text{Water demand of each sector} \tag{7}$$

$$\text{Total water demand} = \text{Agriculture D.} + \text{Domestic D.} + \text{Oil industry D.} + \text{Industrial D.} + \text{Environmental D.} \tag{8}$$

$$\text{Surface water withdraw} = \sum_{i=1}^{n} (\text{water demand}_i \times \text{the share of surface water}) \tag{9}$$

$$\text{Ground water withdraw} = \sum_{i=1}^{n} (\text{water demand}_i \times \text{the share of ground water}) \tag{10}$$

3.1.2. Population Subsystem

Population is one of the factors that affect the water demand (Sušnik *et al.*, 2012). Generally, population is the main driving factor in water demand. Population influence the domestic water demand directly and other sources of water demands indirectly (Davies and Simonovic, 2011). There are some towns and villages on the *Kheirabad river basin*. Most of the domestic water demand at the basin is provided by *Kowsar* dam. Also *Kowsar* dam supplied water to the Persian Gulf littoral cities and ports for nearly 20 years. 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 Eq. 11 as follows:

$$population(t) = population(0) + \int_{t0}^{t} (population\ growth\ rate)dt \tag{11}$$

In this study, the total population is divided into urban and rural population groups according to urbanization rates (Fig. 3). Therefore, the water demand in the urban sector equals urban population multiplier per capita water consumption in the urban sector and similarly

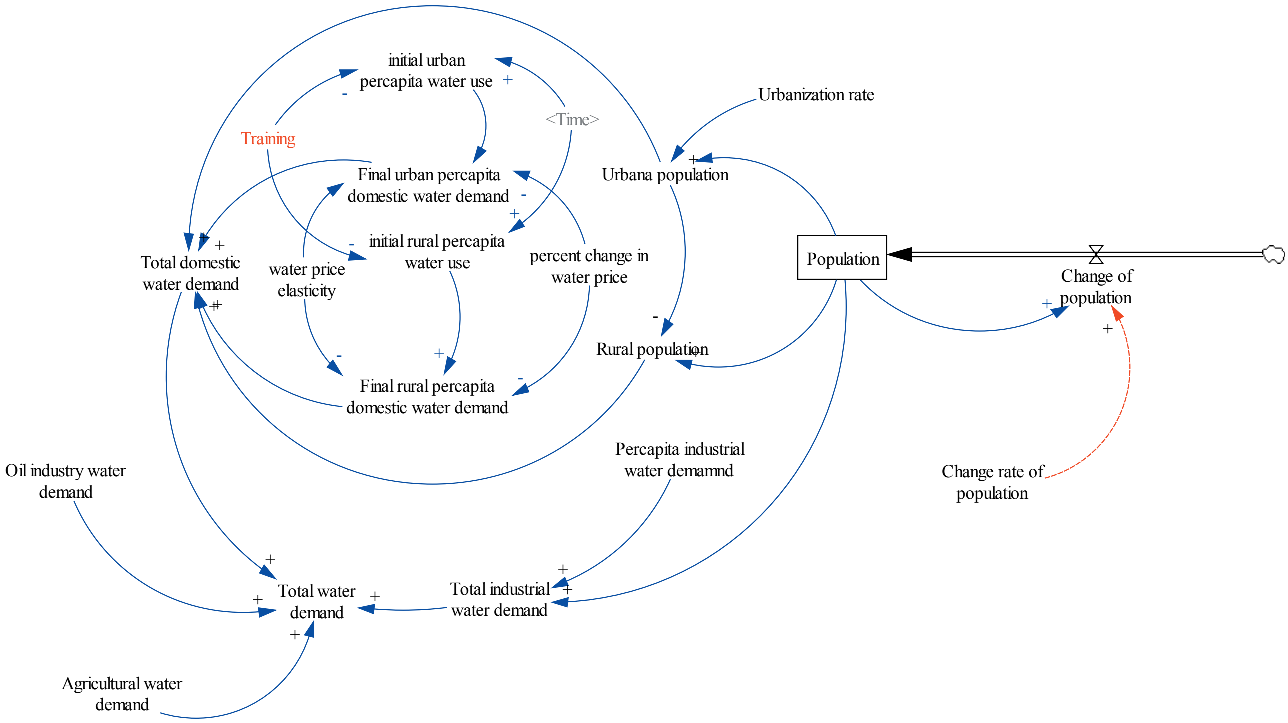

Figure 3. Population subsystem stock and flow diagram.

the water demand in rural sector will be obtained by multiplier of per capita water consumption in the rural sector rural in rural population. The sum of the demand for water in the urban and rural sector constitutes the total domestic demand. It is a fact that water price changes affect water demand. In other words, according to the price elasticity of water demand, we can calculate the feedback of consumer to water price change:

$$E = \frac{\%\Delta Q}{\%\Delta P} = \frac{Q_t - Q_{t-1}}{P_t - P_{t-1}} \times \frac{P_{t-1}}{Q_{t-1}}$$
$$Q_t = Q_{t-1} \times (1 + E \times \frac{P_t - P_{t-1}}{P_{t-1}}) \qquad (12)$$

Where E is the price elasticity of water demand, Q_t is the quantity of demand in period t and p_{t-1} is the price of water in period t-1 (Varian, 1996). Based on the Regional Water Organization of Kogiluyeh and Boyerahmad province (2017), the price elasticity of water demand is considered to be -0.35 in *Kheirabad river basin*.

3.1.3. Agricultural production Subsystem

The agricultural sector is a major consumer of water resources and the change of rivers hydrology conditions, water resources change and climate parameters affect agricultural activities. Climate change affects the water requirement of crops, water consumption and crops yield and consequently agricultural production and farmer's income. Nine crop types are included in the agricultural sub-system, namely wheat, barley, rice, corn, rapeseed, beans, tomato, watermelon and cucumber (Fig. 4). In general, water demand of agricultural sector can be calculated from Eq. 13:

$$\textit{Agricultural water demand} = (\sum_{i=1}^{9} \textit{cropland area}_i \times \textit{water requirement}_i) \,/\, \textit{irrigation efficiency} \qquad (13)$$

Expected agricultural water demand of basin is obtained from sum of calculated demand for all crops. In addition, water requirement has a negative causal relationship with irrigation efficiency. In this research, Nerlove (1956) model was used to model the area under cultivation.

$$Y_t = \gamma\beta_0 + \gamma\beta_1 P_{t-1} + (1-\gamma)Y_{t-1} + \gamma U_t \qquad (14)$$

The model is based on the assumption that farmers determine their optimal cropland area based on the

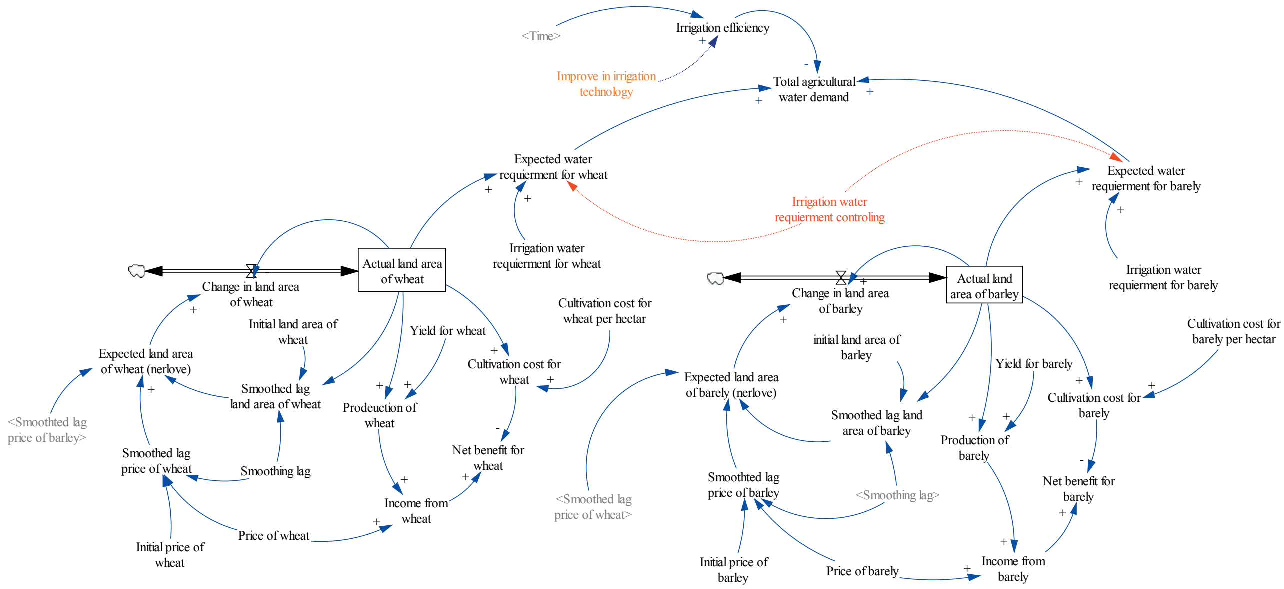

Figure 4. Agricultural production subsystem stock and flow diagram (with two crops).

expected price[4]. In this connection, the price of each crop during the simulation period is predicted applying ARIMA[5] model and entered into the basin SD model as an exogenous variable. As can be seen in equation 14, the lag of dependent variable is considered as an explanatory variable. According to the endogenous nature of this variable, Generalized Method of Moments (GMM) was used to estimate Nerlove model[6].

In the agricultural subsystem production of each crop are calculated based on Eq. 15 via crop yield multiplied by its land area. Following Atherton (2013), population growth due to per capita food consumption increases food demand and the food self-sufficiency index is defined as the ratio of food production to total demand for food. Other possible drivers, for instance international trade, labour productivity and other technological advance, are kept constant during the simulation period.

Food Production = Crop yield × Cropland area
Self-sufficiency index=Food Production / Food Demand (15)
Food Demand = Population × Per capita food consumption

[4] Further research could also be conducted to determine the effectiveness of labor, capital, and other input on cropland area change. but The lag of the cultivated area in the model could represent the farmer behavior and his decisions based on the available facilities.

[5]. Autoregressive Integrated Moving Average – Appendix 1 (Result of real price forecasting)

[6]. We've used the *Eviews9* software to regress this equation.

3.1. 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. 16:

$$SI = [REI \times (1\text{-}VUL) \times (1\text{-}MAX\ DEF)]^{1/3} \tag{16}$$

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.:

$$D = \begin{cases} WD\text{-}WS & if \quad WD>WS \\ 0 & otherwise \end{cases} \tag{17}$$

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

$$REI = \frac{Number\ of\ time\ D = 0}{N} \tag{18}$$

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):

$$VUL = \frac{(\Sigma D)\ /\ Number\ of\ times\ D > 0\ occurred}{Water\ demand} \quad (19)$$

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

$$Max\ Def = \frac{\max(D_{annual})}{Water\ demand} \quad (20)$$

Table 1 shows the initial values of the stock and some key exogenous variables used for the SD model. This study also uses water shortage index (WSI) to address the interaction between supply (WS) and demand (WD) of water (Fig. 5). The water shortage index defines as the ration of water supply and demand (Zarghami and Akbariyeh, 2012). In order to increase water shortage index, both demand and supply management options should be considered. The interaction between water supply and demand is captured using a water supply and demand balance index (Fig. 5) (Langedale *et al*., 2007). The water balance index (BI) increases with the water availability (WS) and decreases with the water demand. When the index is lower than zero or certain value, the water supply and demand management options will be necessary. The demand management options will decrease the water demand, which in turn the index. The supply management options will increase the water supply, which can offset the freshwater withdrawal and increase the water availability (Zhuang, 2014).

$$WSI = \frac{WD}{WS} \quad (21)$$

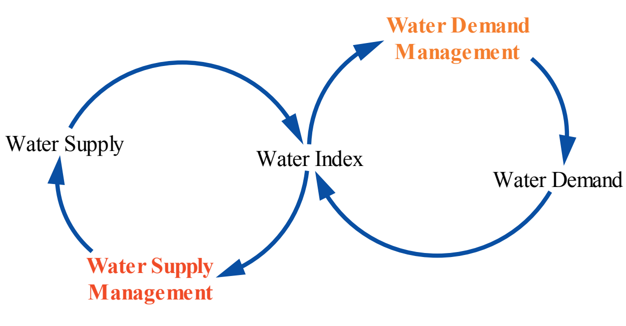

Figure 5. Interaction between water supply and demand.

$$BI = WS\text{-}WD \quad (22)$$

2.2. Policy scenario design

To achieve the high sustainability at the basin, six scenarios is defined based on different levels of irrigation efficiency, water requirement, water price and crops water cropland area. A short description of the scenarios is presented in Table 1.

According to the latest studies conducted into this matter, the average irrigation efficiency in the *Kheirabad river basin* is about 45%. The first policy scenario involves increasing irrigation efficiency as one of the most effective policies for water resources conservation. Therefore, in line with the goals set in the Fifth Development Plan of Iran (Gohari *et al*., 2017) and also the potential irrigation efficiency at the basin, agricultural water use efficiency was increased to 60%. To manage water demand in the agricultural sector, the policy of reduction water requirement of crops by 10% was considered as another scenario. Reducing the water requirement of crops can be achieved by changing irrigation strategies, conservation activities, changing cultivation dates and using drought-tolerant varieties. Since water is the major limiting factor for agriculture production, changing in the crop pattern can be considered as a water resources management policy (Donati, *et al*., 2013). High water requirements of rice and watermelon point out that continued cultivation of these crops may not be justified under climate change from a water management perspective. Therefore, as another scenario we simulate the effect of cropland declining (Excluding rice and watermelon) on water resources availability, water demand and water resources sustainability index at *Kheirabad river basin*. The underlying assumption for this scenario was that current cropland area would decrease.

The Iranian Statistics Center also reports that average per capita water demand in *Kheirabad river basin* is 20 percent higher than the country average. Thus, reduction in average per capita water demand is defined as another policy scenario. As well as, per capita water demand controlling can be achieved through domestic water tariff reform. Based on the goals set in the Fifth Development Plan of Iran, the government was allowed to increase the price of drinking water by 7% annually to promote social justice. Last scenario envisaged water sustainability by decreasing water withdraw of surface and groundwater resources due to applying inter-basin water transfer policy. As more detail, only 70% of the total domestic water demand will come from surface and groundwater resources at the basin, and 30% will be

Table 1. Description of different scenarios.

Policy scenario	Description
Improving irrigation efficiency	Increasing irrigation efficiency parameter to 60% smoothly (50%, 55% and 60%).
Decreasing water requirement of crops	10% reduction in water requirement of crops
Crop pattern	Cultivation of all crops, exclude watermelon and rice
Water price	Increasing price of drinking water by 7% annually
Controlling per capita water consumption	20% reduction in average per capita water demand at the basin
Controlling water withdraw	Only 70% of the total domestic water demand meet from surface and groundwater resources at the basin

met through inter-basin transfer or desalination (Vice-Presidency for Strategic Planning and Supervision, 2017).

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

The system dynamics modeling framework of *Kheirabad river* basin water resources management is presented in Fig. 6.

Some key parameters and stock variables used in the model and their corresponding values are describing in Table 2. Typically, long-term intervals from 10 years (Zarghami and Akbariyeh, 2012) to 100 years (Rehan *et al*., 2011), are used to understand the effects of long-term management options on water system. In this study, a period of 40 years (1992-2031) is considered as the model time boundary and the data of 23 years (1999-2013) are used to validate the designed system dynamics model. According to the available data from water system, time steps are considered annually.

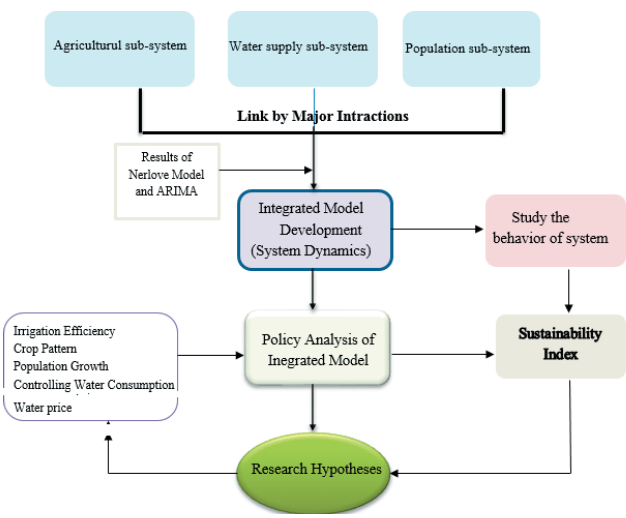

Figure 6. The system dynamics modeling framework of *Kheirabad river basin.*

4. RESULTS

4.1. Model validation

The performance of the model is discussed by comparing model outputs for the selected variables to the corresponding historical data. The surface water availability and population are the key variables demonstrating the performance of the water system. In general, as shown in Fig. 7 and 8, the model performed well in comparison to the historical data.

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 surface water have low values of mean relative errors (less than 10%) and the value of R^2 is calculated to be around 0.73 (Table 3).

4.2. Future simulation

For future simulation, the water demand, water availability and water sustainability index were computed for the baseline scenario. Prior to that, simulations of cropland area, the average production, and food self-sufficiency index for the catchment were presented. Finally, the effect of different water demand management policies previously mentioned on water resources indicators was evaluated.

4.2.1. Cropland area and agricultural production

After testing the reliability of the model, the behavior of the system is then simulated over time to assess the availability of water resources and sustainability index. According to the coefficients obtained from the Nerlove model, the simulated trend of the area under cultivation of selected crops at the basin is presented in the table 4. In order to examine this fact in more detail, it should be noted that the total cropland area at the basin increases

Table 2. The stock and exogenous variables of water system.

Variable type	Variable name		Initial value	Unit	Source
Stock Variable	Population		1.993	Million person	The Statistical Center of Iran 2018
	Surface water		996.54	Mm^3	Regional Water Organization of Kohgiluyeh and Boyerahmad Province 2017
	Cropland area	Wheat	7214	Hectare	The Ministry of Agriculture – Jahad 2018 https://www.maj.ir/
		Barley	973	Hectare	
		Corn	653	Hectare	
		Rice	2830	Hectare	
		Bean	169	Hectare	
		Rapeseed	250	Hectare	
		Watermelon	796	Hectare	
		Cucumber	58	Hectare	
		Tomato	40	Hectare	
Exogenous variable	Per capita industry water use		2.13	m^3	Regional Water Organization of Kohgiluyeh and Boyerahmad Province 2017
	Urban per capita domestic water use		64.3	m^3	
	Rural per capita domestic water use		36.6	m^3	
	Runoff rate		16	%	Regional Water Organization of Kohgiluyeh and Boyerahmad Province 2017
	Percolation rate		12	%	
	Oil industry water demand		31	Mm^3	
	precipitation		Time series	mm	Water Balance Reports 2018
	temperature		Time series	c	
	Irrigation efficiency		45	%	Abbasi *et al.* (2015)
	Area of basin		4232.5	Km^2	Water Balance Reports 2018
	Population growth		1.59	%	The Statistical Center of Iran 2018
	Yield	Wheat	2.93	tone	The Ministry of Agriculture – Jahad 2018 https://www.maj.ir/
		Barley	2.25	tone	
		Corn	6.33	tone	
		Rice	4.44	tone	
		Bean	1.66	tone	
		Rapeseed	1.13	tone	
		Watermelon	38.87	tone	
		Cucumber	33.21	tone	
		Tomato	24.26	tone	
	Gross water requirement (net water requirement/ irrigation efficiency)	Wheat	4123	M^3/hectare	NETWAT Software
		Barley	3516	M^3/hectare	
		Corn	6664	M^3/hectare	
		Rice	11862	M^3/hectare	
		Bean	7193	M^3/hectare	
		Rapeseed	4602	M^3/hectare	
		Watermelon	7694	M^3/hectare	
		Cucumber	8989	M^3/hectare	
		Tomato	9708	M^3/hectare	
Endogenous Variable	The other variables seen in the Stock-Flow diagram are endogenous variables. Relationships related to endogenous variables are presented in equations 1-15.				

from 20.077 thousand hectares in 2020 to 21.049 thousands hectares at the end of the simulation period. The results indicate that the average of total cropland area during simulation period will be 20.506 thousand hectares and the annual growth rate of this variable will be 0.585 percent. Changes in the level of cultivation of agri-

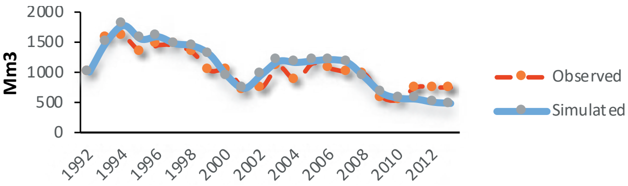

Figure 7. The observed and simulated values of surface water.

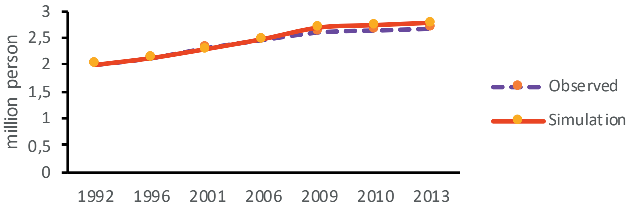

Figure 8. The observed and simulated values of population.

Table 3. Statistical parameters of the model tests.

Variable	R^2	MRE (%)
Surface water	0.73	4.45
Population	0.99	0.86

5. Among selected crops, average production of wheat, watermelon and corn is higher than other crops. The lowest average production is also for beans. The results showed that the average annual production of wheat, watermelon and corn is 34.946, 34.827 and 18.344 thousand tons, respectively. Given this average production, the self-sufficiency index for these crops is equal to 0.597, 1.101, and 0.899, respectively. The self-sufficiency index of greater than 1 for rice and watermelon means that this basin is a potential exporter for these products and there are excess productions available for exporting to adjacent basins.

4.2.2. Water demand

The simulated population at the basin is reported in table 6. According to available reports, the annual population growth rate at the basin was considered to be 1.59 percent that assumed to be constant over the period 2018-2030. Due to this growth rate, total population increases from 3.141 million in 2020 to 3.678 million at the end of the simulation period. According to the SD model, both per capital water consumption in urban and rural areas and population growth affect total domestic water demand in *Kheirabad river basin*. It can be seen from table 6 that domestic water demand will increase from 173.369 Mm^3 in 2020 to 205.662 Mm^3 at the end of simulation period. The annual average of domestic water demand at the basin will be 184.983 Mm^3 during the 2018-2031. Another important finding is that 22 percent of average domestic water demand is related to rural household and 78 percent of that is related to urban household at the basin. Changes in industrial water demand is also as a function of population in water system designed. Table 6 indicates a slight increase occurring in both industrial and household water demands and thus, total water demand at the basin is likely to increase during simulation period. The results of this research support the idea that the gap between supply and demand for water increases continuously and the water system becomes more vulnerable in the future. The results corroborate the finding of a great deal of the previous work in this field, e.g. Gohari *et al.* (2017) and Kotir *et al.* (2017). Considering available surface water for environmental and oil industry water demand,

Table 4. Results of cropland area and agricultural water demand (Thousand hectare).

Crops	2020	2022	2024	2026	2028	2030	Average
Wheat	11.653	12.301	12.159	11.589	11.663	12.411	11.927
Barely	1.183	1.180	1.181	1.185	1.185	1.181	1.182
Rice	2.701	2.802	2.714	2.724	2.722	2.711	2.712
Corn	2.819	2.854	2.897	2.945	2.979	2.995	2.898
Bean	0.175	0.175	0.175	0.175	0.176	0.176	0.175
Rapeseed	0.393	0.397	0.396	0.393	0.394	0.399	0.394
Cucumber	0.151	0.163	0.163	0.150	0.149	0.161	0.157
Tomato	0.112	0.113	0.113	0.112	0.112	0.113	0.113
Watermelon	0.889	0.910	0.908	0.885	0.883	0.903	0.896
Total	20.077	20.797	20.706	20.159	20.263	21.049	20.506

Table 5. Average food production and self-sufficiency index at the Basin.

Crops	Average Production (Thousand Tone)	Self-Sufficiency Index
Wheat	34.946	0.597
Barely	2.659	0.350
Rice	12.041	1.078
Corn	18.344	0.899
Bean	0.290	0.325
Rapeseed	0.445	0.315
Cucumber	5.213	0.240
Tomato	2.741	0.188
Watermelon	34.827	1.101

Table 6. Results of simulated population (million person) and water demand (Mm^3).

Variables		2020	2022	2024	2026	2028	2030	Average
	Population	3.141	3.242	3.346	3.453	3.563	3.678	
Water demand	Agricultural water demand	306.434	313.562	313.154	308.241	309.320	316.746	311.198
	Domestic water demand	173.369	179.914	186.706	193.754	200.101	205.662	184.983
	Industrial water demand	37.690	37.905	38.126	38.354	38.590	38.833	38.138
	Sum of water demand	517.493	531.381	537.986	540.529	548.011	561.241	534.319

respectively 79 Mm^3 and 31 Mm^3, the amount of total water demand at the basin in 2020 is 627.493 Mm^3 and reach to 671.241 Mm^3 at the end of simulation period.

4.2.3. Water availability

The results of table 7 show that an increase in agricultural water demand along with population growth at the basin can increase the surface water withdraw and decrease surface water availability in the study area. In other words, the amount of available surface water decreases from 487.701 Mm^3 in 2020 to 433.893 Mm^3 at the end of simulation period. The average annual changes of this variable during 2018-2031 will be -1.23 percent. Compared with available surface water, the average annual change of surface water withdraw is estimated about +0.75 percent. As shown in Table 7, withdraw of water at the basin increase by 0.75% on average during 2018-2031 and reaches about 324.176 Mm^3 at the end of the simulation period. An increase in the population and cropland area in the basin increase the total water demand by almost 0.758 % annually. Therefore, the upward trend of total water demand leads to an increase in surface water withdraw. Withdraw of surface water is affected by the demand of the household, industrial and agricultural sectors. Also, water withdrawal for environment uses is considered a constant amount (about 79 Mm^3 yearly), according to Kohgiluyeh and Boyerahmad provincial water organization. Due to population growth (considering the growth rate of 1.59%) and also upward trend of cropland area the demand for household, industrial and agricultural consumption increases directly and the withdrawal of water resources increases eventually. Therefore, it can be concluded that water demand control policy has a positive effect on decreasing in withdraw of water and sustainable water resources management.

The simulated values for the groundwater withdrawal in Figure 8indicate how changes in water demand can affect the behavior of groundwater availability. The volume of groundwater withdrawal at the beginning of the simulation period, equals to 212.809 Mm^3 and with growth of 10.29% reach to peak in 2030 about 234.396 Mm^3. The average annual percentage change of withdrawal of groundwater resources is calculated about 0.837%. As can be seen in Fig. 9, the groundwater balance at the basin is negative during the simulation period, i.e. the trend of groundwater withdrawal is increasing and the outflows are more than the inflows.

4.2.4. Water indices

Figure 10 illustrates the trend of water shortage index and water balance index in *Kheirabad river basin*. As can be seen in the figure, the water shortage index increases and the water balance index decreases over time as water demand goes up as results of population growth and upward trend of cropland area. At the end of simulation period the demand and supply balance index are expected to be negative. It means that, in some years, the value of water demand becomes bigger than water supply at the basin. The downward trend of water balance index triggers the water supply or demand management options. The demand management options can decrease the water demand, which in turn increases the index.

Table 7. Results of available surface water and withdraw simulation - Mm^3.

	2020	2022	2024	2026	2028	2030	Percent average change
Available surface water	487.701	478.543	467.777	455.085	443.311	433.893	-1.234
Surface water withdraw	298.988	306.258	309.956	311.572	316.252	324.176	+0.756

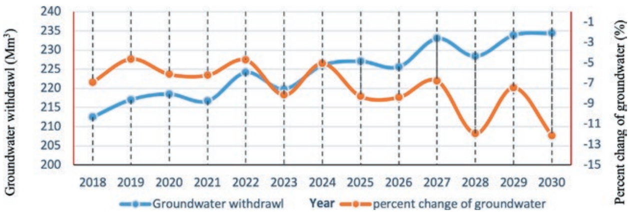

Figure 9. The result of simulated values of groundwater changes.

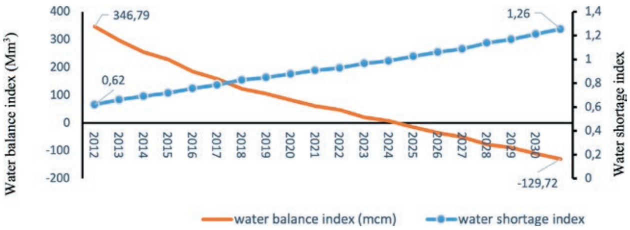

Figure 10. The result of simulated values of groundwater changes.

The next system dynamics model output displayed here is the sustainability index. As introduced in pervious section, this index is computed as combination of three other indices (Reliability index, Vulnerability index, Max deficit). The results in table 8 indicate that the sustainability index at *Kheirabad river basin* will be 0.703 if current environmental conditions within the basin would remain the same without any changes (Baseline). As shown, values of reliability, vulnerability and max deficit indices are estimated to be 0.50, 0.119 and 0.213 respectively. In short, the simulation confirms that the growing demand for water is acting to exacerbate the problems of meeting the growing water demand of Kheirabad river basin.

The results represent the inability of water resources system to meet the increasing water demand in *Kheirabad river basin*. The positive max deficit index indicates that in some years, the value of water demand surpassed its supply value and the system encountered to water shortage. Therefore, according to the results, it is projected the increasing demand for water, due to population growth and upward trend of cropland area, is unlikely to be met using available water resources during the simulation period.

Table 8. Water indices at Kheirabad river basin.

	Reliability Index	Vulnerability Index	Max Deficit Index	Sustainability Index
Water Index	0.50	0.119	0.213	0.703

4.3. Policy scenario analysis

The impacts of water resources management policies on water system can be tracked through the calculation of water resource indices. As showed in Table 9, the implementation of demand control policies likely help meets the growing water demand and the sustainability index for Kheirabad water system increases in comparison with the baseline. As more detail, by increasing irrigation efficiency up to 50%, water resource sustainability index increased to 0.897. Therefore, it can be stated that the effectiveness of this policy on water resource sustainability index within the basin is 27.59%. After increasing irrigation efficiency to 55%, the reliability index increased to 0.857 and vulnerability index decreased to 0.014. Under these circumstances the water resource sustainability index will be 0.940. However, even under this scenario water shortage mater. The highest sustainability index (the lowest vulnerability index) belongs to business as usual conditions along with increasing irrigation efficiency up to 60%. The results also revealed that a 10% reduction in water requirement of crops increases the sustainability water index to 0.857 and decreases vulnerability index to 0.026, compared to business as usual condition without any actions. Although this policy has a significant impact on improving the water system situation in terms of sustainability, it has still been vulnerable in terms of meeting water demand. Therefore, in order to increase the system's ability to respond water demand in the long-term, complementary strategies are needed along with reducing the water requirement of crops at the basin. The results also showed that the reliability and sustainability index of water resources will be 1 after removal of crops with high water requirement. Agricultural water demand decreases as a result of changing crop pattern within the basin. Therefore, it is expected that the gap between supply and demand for water decreases continuously and the water system becomes more sustainable in the future. 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 to improve the water sustainability index even under population growth and agricultural development.

The findings also reveal that, by controlling water withdraw as a water management policy at the basin, surface water outflow decreases during the simulation period compared with the baseline condition and the water system can be in a better situation in terms of sustainability. Increasing water storage is expected to increase the ability to meet the demand for water in

Table 9. Water indices under different scenarios.

Policies		Reliability Index	Vulnerability Index	Max Deficit Index	Sustainability Index	Priority
Improving irrigation efficiency	50%	0.786	0.029	0.053	0.897	5
	55%	0.857	0.014	0.015	0.940	3
	60%	1.00	0.00	0.00	1.00	1
Decreasing water requirement of crops		0.857	0.026	0.037	0.930	4
Crop pattern		1.00	0.00	0.00	1.00	1
Water price		0.571	0.104	0.180	0.749	6
Controlling per capita water consumption		0.929	0.020	0.020	0.963	2
Controlling water withdraw		1.00	0.00	0.00	1.00	1

the basin in this condition. According to the Table 9, a reduction in per capita water demand and the economical instruments such as domestic water pricing under competition structure would help to improve the sustainability index to 0.963 and 0.749, respectively.

5. DISCUSSIONS

As mentioned in the literature review, changes in water resources exhibit dynamic behaviors as such resources are affected by many socio-economic and climatic factors over time. Because of complicated interactions and feedbacks among the factors in the water system, a comprehensive and interaction-based approach is needed to understand the consequences of a change in the system. So, in this research, an integrated system dynamics simulation model was developed to examine the feedback processes and interaction among the population, water resources, and agricultural production in sub-sectors of *Kheirabad river basin* in Iran. An initial objective of the project was to identify the behavior of the water system at the basin over time. With respect to the first research aim, it was found that water demand increases as the population growth and agricultural development occur. Under such conditions, the withdrawal of surface and groundwater increases over time which is consistent with the Gohari *et al.* (2017) results for the *Zayandehrud river basin*. The most interesting finding is that population growth contributes to 0.75% annually increase in water demand and 1.23% annually decrease in available surface water during the simulation period. Regarding that the population of the region is expected to increase by 1.87% during 2021-2027, this may put more pressure on the water resources at the basin. A growing population would be a threat for water use sustainability especially if other measures like increasing water use efficiency are not taken into consideration. Another important finding is that the water sustainability index at the basin is 0.703 if the current environmental and socioeconomic condition within the basin would remain the same without any policy change. Therefore, the water supply at the basin can likely be unsustainable and total water demand exceeds the water supply. This finding confirms the results of recent model-based studies and assessments that analyzed the impact of climate change and population growth on water resource availability (e.g., Kotir *el al*., 2016; Gohari *et al*., 2017; Zubaidi *et al*., 2020). It cannot be denied that the water system is vulnerable (vulnerability index is more than zero) due to an imbalanced supply and demand, caused by increasing population and cropland area. This finding is also reported by Madani (2014) and Nkegbe & Shankar (2014). In other words, both of the supply and demand side of the water system is threatening since a growing water demand is accompanied by a possible decrease in water availability caused from more intensive surface and groundwater use. Regarding the widening supply-demand gap, to meet the water demand in the near future, demand management policies are needed. So, the present study is designed to determine the effect of water demand and supply management policies on the behavior of the water resources system at the basin. Especially, given the possible increasing water shortage, water management policies should concentrate on demand side of water use to address the problem. According to the results, a reduction in per capita water demand can play a significant role in decreasing vulnerability and increasing the sustainability indices. This finding is also reported by Stavenhagen *et al.* (2018). However, there is a larger room in agriculture uses where the water use efficiency is much lower than the global ones. It is worth noting that drinking water is supplied by the public sector and the price paid by the consumers' accounts for a slight part of the water costs. Thus, this may indicate that there is considerable room for water demand management even in drinking water demand.

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 while the average irrigation efficiency is less than 35%, and only 5% of the farmed area enjoys modern irrigation system (Madani, 2014). Based on the results, the most effective policy scenario on water management at the basin related to improving irrigation efficiency and crop pattern. In more detail the improving irrigation efficiency up to 60% can bring the water resources system of the *Kheirabad River Basin* to a sustainable state. Besides, the results revealed that crop pattern change and remove rice and watermelon from the cultivation pattern has a positive significant effect on the sustainability index. This study supports evidence from previous observation (e.g. Donati *et al*., 2013 and Hashemi *et al*., 2019). Considering the expected negative effects of adopting this strategy on the production and income of farmers at the basin, the development of non-agricultural activities and small conversion industries in rural areas to compensate for the damage caused by possible variability of weather conditions can be effective.

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. Comparison of water resources sustainability index after the implementation of various policies also confirms the fact that controlling per capita water consumption can be high effective in managing water demand. Moreover, the economical instruments such as domestic water pricing under competition structure, can significantly control water demand toward sustainable management of water. What is surprising is that water pricing has the least efficient in water demand controlling. This is basically because of price inelastic demand at the basin. Therefore, in summary, the effectiveness of water demand management policies in the domestic sector is expected. 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 irrigation water pricing and conservation agriculture (such as zero tillage, mulching and crop rotation). Also, as a policy scenario in this study, it is assumed that 30% of domestic water demand can be met from outside the basin. The results of this study showed that supply-oriented policies such as inter-basin transfer or urban wastewater reuse to reduce the surface and groundwater withdrawal, regardless of the cost of their implementation, can contribute to the sustainability of the water resources system.

6. CONCLUSION

Generally, for managers, a simulation model for the water system is extremely useful. The simulation model allows to look at the interaction of different elements over time and helps you simulate how different management decisions will affect the system. Reducing available water resources is a very serious challenge facing policymakers and planners of water resources in Iran. This mater underlines the need for sustainable management of this vital resource. This study applies system dynamics approach to analyze the behaviour of water system in *Kheirabad river basin* located in southwestern Iran. The study is an attempt to answer this question that can the *Kheirabad river basin* reconcile its available water supply with the growing demand for water. Although many studies have used the system dynamics method to manage water resources, there is a large difference between the structure of the designed model and the variables used in these studies. The differences in studies are in terms of objectives, evaluated policies, and temporal and spatial boundaries. The fact of the matter is that a model can be designed for each basin to suit the economic, social, and environmental characteristics. This is one of the ways to avoid policy resistance in water management. The designed system dynamics model was used to simulate the outcomes of different policy scenario. The results demonstrate that all scenarios reach limits to growth, however, water sustainability index was maximized under improving irrigation efficiency and changing crop patterns at the basin. In other words, the variables of the agricultural sub-sector can be considered as one of the high leverage points in the water resources management system of the *Kheirabad river basin*. It confirms that with system thinking and holistic worldview, policymakers can identify the high leverage points in systems for each basin and avoid policy resistance. Finally, our study is the first attempt at modeling in the *Kheirabad river basin* in Iran that by engaging stakeholders in model development, we have implemented a process compatible with improving stakeholder understanding of the dynamic behaviour of the basin over time. There are, however, some limitations of our study that could be addressed in order to add more precision to our results. This paper has focused on the sustainability index in baseline weather condition. Further research can also focus on climate variability condition along with population growth and agricultural development. Depending on the climatic conditions and the type of cultivation in each region, climate change can have negative and positive effects on agricultural production. Therefore, it is necessary to study the effects of climate change on the yield of strategic crops for regions or provinces (even in different sub-basins) separately in order to obtain the best cultivation pattern for vulnerable areas. Meanwhile, the economic tools for water resources management can also be considered for agricultural sub sector to assess the impacts of agricultural water price reform on system behavior. Considering farmers' behavior under various conditions, including changes in available water resources, may contribute to the flexibility of the model. Last but not least, 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.

DATA AVAILABILITY STATEMENTS

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Abbasi, F., Sohrab, F., & Abbasi, N. (2017). Evaluation of irrigation efficiencies in Iran. *Irrigation and Drainage Structures Engineering Research*, *17*(67), 113-120.

AghaKouchak, A., Norouzi, H., Madani, K., Mirchi, A., Azarderakhsh, M., Nazemi, A., ... & Hasanzadeh, E. (2015). Aral Sea syndrome desiccates Lake Urmia: call for action. *Journal of Great Lakes Research*, *41*(1), 307-311.

Archibald, T. W., & Marshall, S. E. (2018). Review of mathematical programming applications in water resource management under uncertainty. *Environmental Modeling & Assessment*, *23*(6), 753-777.

Atherton, J. T. (2013). *A System Dynamics Approach to Water Resources and Food Production in the Gambia* (Doctoral Dissertation, the University of Western Ontario).

Balali, H., & Viaggi, D. (2015). Applying a System Dynamics Approach for Modeling Groundwater Dynamics to Depletion under Different Economical and Climate Change Scenarios. *Water, 7,* 5258-5271.

Berger, T., Birner, R., Mccarthy, N., DíAz, J., & Wittmer, H. (2007). Capturing the complexity of water uses and water users within a multi-agent framework. *Water resources management*, *21*(1), 129-148.

Brown, C. M., Lund, J. R., Cai, X., Reed, P. M., Zagona, E. A., Ostfeld, A., ... & Brekke, L. (2015). The future of water resources systems analysis: Toward a scientific framework for sustainable water management. *Water resources research*, *51*(8), 6110-6124.

Cai, X., Wallington, K., Shafiee-Jood, M., & Marston, L. (2018). Understanding and managing the food-energy-water nexus–opportunities for water resources research. *Advances in Water Resources*, *111*, 259-273.

Cakir, R., Raimonet, M., Sauvage, S., Paredes-Arquiola, J., Grusson, Y., Roset, L., ... & Sánchez-Pérez, J. M. (2020). Hydrological alteration index as an indicator of the calibration complexity of water quantity and quality modeling in the context of global change. *Water*, *12*(1), 115.

Clifford Holmes, J. K., Slinger, J. H., Musango, J. K., Brent, A. C., & Palmer, C. G. (2014). Using system dynamics to explore the water supply and demand dilemmas of a small South African municipality. In *32nd International Conference of the System Dynamics Society, Delft, The Netherlands, 20-24 July 2014; Authors version*. System Dynamics Society.

Darbandsari, P., Kerachian, R., Malakpour-Estalaki, S., & Khorasani, H. (2020). An agent-based conflict resolution model for urban water resources management. *Sustainable Cities and Society*, *57*, 102112.

Davies, E. G., & Simonovic, S. P. (2011). Global water resources modeling with an integrated model of the social–economic–environmental system. *Advances in water resources*, *34*(6), 684-700.

Donati, M., Bodini, D., Arfini, F., & Zezza, A. (2013). An integrated PMP model to assess the development of agro-energy crops and the effect on water requirements. *Bio-based and Applied Economics*, *2*(3), 301-321.

Fazel, N., Haghighi, A. T., & Kløve, B. (2017). Analysis of land use and climate change impacts by comparing river flow records for headwaters and lowland reaches. *Global and Planetary Change*, *158*, 47-56.

Ford, A. and Ford, F.A. (1999). *Modeling the environment: an introduction to system dynamics models of environmental systems*. Island press.

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society*, *48*(10), 1037-1041.

Frank, M. (2000). Engineering systems thinking and systems thinking. *Systems Engineering*, *3*(3), 163-168.

Gohari, A., Mirchi, A., & Madani, K. (2017). System dynamics evaluation of climate change adaptation strategies for water resources management in central Iran. *Water Resources Management*, *31*(5), 1413-1434.

Goldani, M., Amadeh, H., & Zamanipour, M. (2011). A system dynamics approach in water resource management and government subsidy policy: A case study of Tajan basin in tran. In *the 29th International Conference of the System Dynamics Society. Washington, DC* (pp. 24-28).

Hashemi, M., Zadeh, H. M., Arasteh, P. D., & Zarghami, M. (2019). Economic and environmental impacts of cropping pattern elements using systems dynamics. *Civil Engineering Journal*, *5*(5), 1020-1032.

Hashimoto, T., Stedinger, J. R., & Loucks, D. P. (1982). Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water resources research*, *18*(1), 14-20.

Hassanzadeh, E., Elshorbagy, A., Wheater, H., & Gober, P. (2014). Managing water in complex systems: An integrated water resources model for Saskatchewan, Canada. *Environmental Modelling & Software*, *58*, 12-26.

Hassanzadeh, E., Zarghami, M., & Hassanzadeh, Y. (2012). Determining the main factors in declining the Urmia Lake level by using system dynamics modeling. *Water Resources Management*, *26*(1), 129-145.

Keyhanpour, M. J., Jahromi, S. H. M., & Ebrahimi, H. (2021). System dynamics model of sustainable water resources management using the Nexus Water-Food-Energy approach. *Ain Shams Engineering Journal*, *12*(2), 1267-1281.

Klemeš, V., Srikanthan, R., & McMahon, T. A. (1981). Long-memory flow models in reservoir analysis: What is their practical value?. *Water Resources Research*, *17*(3), 737-751.

Kotir, J. H., Smith, C., Brown, G., Marshall, N., & Johnstone, R. (2016). A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana. *Science of the Total Environment*, *573*, 444-457.

Loucks, D. P. (1997). Quantifying trends in system sustainability. *Hydrological Sciences Journal*, *42*(4), 513-530.

Madani, K. (2014). Water management in Iran: what is causing the looming crisis?. *Journal of environmental studies and sciences*, *4*(4), 315-328.

Madani, K., & Mariño, M. A. (2009). System dynamics analysis for managing Iran's Zayandeh-Rud river basin. *Water resources management*, *23*(11), 2163-2187.

Mahdavinia, R., & Mokhtar, A. (2019). Dealing with sustainability in groundwater management using system dynamics approach, a case study in Iran. *Sustainable Water Resources Management*, *5*(4), 1405-1417.

McMahon, T. A., Adeloye, A. J., & Zhou, S. L. (2006). Understanding performance measures of reservoirs. *Journal of Hydrology*, *324*(1-4), 359-382.

Mirchi, A. (2013). *System dynamics modeling as a quantitative-qualitative framework for sustainable water resources management: Insights for water quality policy in the great lakes region* (Doctoral dissertation, Michigan Technological University).

Moy, W. S., Cohon, J. L., & ReVelle, C. S. (1986). A programming model for analysis of the reliability, resilience, and vulnerability of a water supply reservoir. *Water resources research*, *22*(4), 489-498.

Mulwa, F., Li, Z., & Fangninou, F. F. (2021). Water Scarcity in Kenya: Current Status, Challenges and Future Solutions. *Open Access Library Journal*, *8*(1), 1-15.

Nkegbe, P. K., & Shankar, B. (2014). Adoption intensity of soil and water conservation practices by smallholders: evidence from Northern Ghana. *Bio-based and Applied Economics Journal*, *3*(1050-2016-85757), 159-174.

Pluchinotta, I., Pagano, A., Giordano, R., & Tsoukiàs, A. (2018). A system dynamics model for supporting decision-makers in irrigation water management. *Journal of environmental management*, *223*, 815-824.

Qin, H. P., Su, Q., & Khu, S. T. (2011). An integrated model for water management in a rapidly urbanizing catchment. *Environmental modelling & software*, *26*(12), 1502-1514.

Regional Water Organization of Kogiluyeh and Boyer ahmad province. (2017). http://www.kbrw.ir/SC.php?type=static&id=2.

Rehan, R., Knight, M. A., Haas, C. T., & Unger, A. J. (2011). Application of system dynamics for developing financially self-sustaining management policies for water and wastewater systems. *Water research*, *45*(16), 4737-4750.

Saif, Y., Almansoori, A., Bilici, I., & Elkamel, A. (2020). Sustainable management and design of the energy-water-food nexus using a mathematical programming approach. *The Canadian Journal of Chemical Engineering*, *98*(10), 2056-2078.

Sandoval-Solis, S., McKinney, D. C., Teasley, R. L., & Patino-Gomez, C. (2011). Groundwater banking in the Rio Grande basin. *Journal of Water Resources Planning and Management*, *137*(1), 62-71.

Senge, P. M., & Forrester, J. W. (1980). Tests for building confidence in system dynamics models. *System dynamics, TIMS studies in management sciences*, *14*, 209-228.

Speelman, S., & Veettil, P. C. (2013). Heterogeneous preferences for water rights reforms among smallholder irrigators in South Africa. *Bio-based and Applied Economics*, *2*(2), 131-149.

Statistical Center of Iran. (2018). https://www.amar.org.ir.

Stavenhagen, M., Buurman, J., & Tortajada, C. (2018). Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. *Cities*, *79*, 187-195.

Stavenhagen, M., Buurman, J., & Tortajada, C. (2018). Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. *Cities*, *79*, 187-195.

Sterman, J. D. (2001). System dynamics modeling: tools for learning in a complex world. *California management review*, *43*(4), 8-25.

Sun, Y., Liu, N., Shang, J., & Zhang, J. (2017). Sustainable utilization of water resources in China: A system dynamics model. *Journal of cleaner production*, *142*, 613-625.

Sušnik, J., Vamvakeridou-Lyroudia, L. S., Savić, D. A., & Kapelan, Z. (2012). Integrated System Dynamics Modelling for water scarcity assessment: Case study of the Kairouan region. *Science of the total environment*, *440*, 290-306.

Vallino, E., Ridolfi, L., & Laio, F. (2020). Measuring economic water scarcity in agriculture: a cross-country empirical investigation. *Environmental Science & Policy*, *114*, 73-85.

Varian, H. R. (1996). *Intermediate Microeconomics: A Modern Approach, WW Norton&Company*. New York.

Ventana Systems Inc. (2011). Vensim Reference Manual. Ventana System Inc.

Vice-Presidency for Strategic Planning and Supervision. (2017). The fifth five-year development plan of the Islamic Republic of Iran (2015–2020). Tehran, Iran.

Xiong, W., Li, Y., Pfister, S., Zhang, W., Wang, C., & Wang, P. (2020). Improving water ecosystem sustainability of urban water system by management strategies optimization. *Journal of environmental management*, *254*, 109766.

Zeng, Y., Li, J., Cai, Y., Tan, Q., & Dai, C. (2019). A hybrid game theory and mathematical programming model for solving trans-boundary water conflicts. *Journal of Hydrology*, *570*, 666-681.

Zhuang, Y. (2014) *A system dynamics approach to integrated water and energy resources management* (Graduate Theses and Dissertations).

Zubaidi, S. L., Ortega-Martorell, S., Al-Bugharbee, H., Olier, I., Hashim, K. S., Gharghan, S. K., ... & Al-Khaddar, R. (2020). Urban water demand prediction for a city that suffers from climate change and population growth: Gauteng province case study. *Water*, *12*(7), 1885.

APPENDIX

Table A1. Real prices of agricultural products (Rial/Kilogram)-ARIMA forecasting.

Crops	1992	1995	1998	2000	2002	2004	2006	2007	2008	2009	2010	2011
Wheat	43.17	41.78	49.05	44.14	46.46	43.27	47.35	44.72	46.16	44.73	45.97	47.05
Barely	33.54	35.22	37.60	35.43	33.24	33.14	35.05	33.62	36.92	33.68	36.77	35.80
Rice	76.77	106.53	90.74	84.73	75.09	79.98	99.38	84.39	106.95	88.17	90.30	99.59
Corn	37.97	36.97	41.44	38.32	37.55	37.86	38.73	37.66	40.51	37.58	39.67	38.52
Cucumber	42.17	22.58	24.18	33.79	34.03	33.39	34.29	37.28	33.53	36.60	35.19	33.85
Bean	139.82	71.77	90.41	116.57	92.47	76.43	90.54	100.49	104.42	100.40	92.26	85.38
Tomato	43.89	33.13	32.04	28.92	30.17	30.69	31.22	30.10	30.05	31.10	29.54	30.92
Watermelon	19.83	22.91	13.41	19.79	19.95	22.02	18.21	23.78	16.78	19.83	20.31	18.08
Rapeseed	117.14	81.31	89.66	87.88	103.32	94.54	83.68	105.63	95.33	92.56	92.47	83.49
Crops	2012	2015	2018	2020	2022	2024	2026	2027	2028	2029	2030	2031
Wheat	44.13	45.28	46.28	44.68	44.80	46.56	46.80	45.30	45.31	46.83	44.43	46.52
Barely	35.25	37.97	37.40	37.21	34.99	33.04	33.27	35.23	35.41	33.77	37.27	34.05
Rice	77.90	79.41	91.46	80.13	83.06	98.02	100.10	85.17	84.53	97.99	77.28	94.38
Corn	37.97	40.02	39.92	40.23	38.78	37.46	37.65	39.20	39.21	37.66	40.33	37.44
Cucumber	35.06	34.94	32.34	36.38	36.48	32.97	31.78	35.43	35.01	31.94	36.90	32.49
Bean	82.92	96.15	92.03	86.69	90.97	95.14	91.85	89.70	88.82	89.49	91.13	92.75
Tomato	30.38	29.65	29.59	29.88	31.00	31.05	29.95	31.18	29.57	30.78	30.53	29.69
Watermelon	21.80	21.19	18.57	21.54	21.51	17.76	17.30	20.33	20.34	17.27	22.26	17.82
Rapeseed	106.61	94.44	95.64	96.13	105.51	86.34	85.68	103.79	97.18	85.11	97.79	87.45