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System dynamics model of sustainable water resources management using the Nexus Water-Food-Energy approach

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ABSTRACT

This research has investigated the simulation of sustainable water resources management to assess the impact of socio-economic development on water, food and energy resources security in Khuzestan Province in Iran. To achieve this goal, after simulation of the water-food-energy system dynamics model, taking into account results of the sensitivity analysis, development of water resources sustainability policy-making was elaborated in the form of four strategies of water demand, water supply, food resource and energy demand management, as well as combined policies. The simulation results of the proposed solutions were selected to be a combination of the strategies of water demand and food resources management as the best policies. Hence, 16% increase in irrigation efficiency, 10% improvement in cultivation patterns, 6% reduction in agricultural products losses, 5% decrease in food demand due to food losses, and 5% annual increase in the performance of agriculture are selected as sustainable water resources management policies.

1. Introduction

About 80 million people are added to the world population each year, and water consumption is increased annually by 1-percent on average throughout the world [1]. With the current trend of water consumption continuing, only 60 percent of the water needed will be available to the world by 2030 if adopting the right policies fails [2]. According to FAO[1], in order to satisfy the demands of population growth by 2050, the agriculture sector is required to increase its production by 60 percent [3]. Likewise, energy consumption will be increased by about 50 percent by 2035 according to the reports by the International Energy Agency [4]. In order to take measures to address the link between water and economic development, experts at the World Economic Forum in 2011 reached the agreements that led to proffering of Nexus Water-Food-Energy (WFE) approach [5]. The Nexus WFE approach identifies the interconnection of water, food and energy in terms of time and place. The goals of the Nexus approach are to improve the security of water, food and energy resources, to determine the path for external communications, and to make cross-sector decisions considering the link in between, and to support the move towards sustainability. Therefore, the Nexus approach provides the initials required for sustainable management of the limited existing resources with integration. In fact, the effects of decision-making on other components in one sector are made transparent using this approach, and by anticipating the potentials and synergizing cross-sector knowledge, designing, evaluating, and prioritizing of various options is made. As the demand grows, the competition over resources will also be increased. Ensuring the availability of water, food and energy as well as the security of all three sectors without reducing natural resources is recognized as a major challenge in Asia. There is a need for a deep understanding of the security nexus among water, food and energy resources in Asia [6]. The increasing scarcity of and dependence on the resources, the rival consumers, and the failure to succeed in segment-centered strategic management are factors that can highlight the integral importance of the link between WFE resources [7]. The dependence

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[1] Food and Agriculture Organization

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Table 1
WFE nexus components [8].

	Water	Food	Energy
Water	• water treatment • wastewater treatment • water desalination	• irrigation • food processing	• cooling systems of geothermal and nuclear power plants • hydroelectric power generation • fossil fuel production • extraction processes
Food	• water pollution	• animal feed	• bioenergy production • biofuel production
Energy	• groundwater pumping • water distribution • water treatment • wastewater treatment • drainage systems • desalination	• fertilizer preparation • agricultural machinery • transportation • cooling systems for food storage • food processing	• heat for geothermal power plants • fuel for the extraction processes

of WFE resources and the relationships and components of the links vary in different zones of time and place. Table 1 briefly displays some identified components of WFE resources link.

Most of the existing studies on identifying the links between sources are distinctly related to Water-Food (WF) or Water-Energy (WE) links. Water-Food (WF) studies are vastly recognized. A great deal of the world water consumption (about 60 to 80 percent) is associated with the irrigation of crops [9]. Since agriculture accounts for the most prominent consumer in most water basins, extensive studies have been conducted in this regard. These studies focus on various aspects of the link including optimization of agriculture water use, taking into account the cultivated area [10–12], fluctuations of the quality of return flow agriculture water [13], examining the relationships between virtual food and water exports [14–16], reducing the use of high water demand crops as well as shifting product assortment to low water demand crops and assessing the effects of food consumption patterns on water resources[17]. There are limited Water-Energy (WE) studies compared to Water-Food (WF) studies. These studies encompass different topics including development of water treatment infrastructure [18], improving irrigation efficiency [19], improving energy efficiency in water supply systems and pumping system planning for optimizing energy consumption [20], and water demand for hydroelectric power plant and biofuel production [21]. Some of these studies have also evaluated and estimated energy consumption in water supply stages [22,23], while some other studies have focused on water consumption for generating energy like virtual water and energy [24], carbon emission and renewable energies [25,26], and others have also added economic issues related studies [27,28]. Food-Energy (FE) studies have focused on improving energy use efficiency in the cultivation process, improving the quality of chemical fertilizers, and energy consumption of crop production [29]. In addition to the mentioned studies, a number of other studies have concurrently addressed the Nexus WFE, some being qualitative, others quantitative, and a limited number in modeling and simulation, most of which were accomplished in a restricted scale of place, such as new approaches for efficient water use and optimal land allocation for biofuel production [30,31], analysis of sugarcane and other industrial plants as alternative energy sources [32], evaluation of the improvement of Irrigation Productivity and Groundwater Management, Energy Consumption and Carbon Emission[33]. Others designed qualitative model studies of the interrelationships between WFE resources with emphasis on water, energy, land use and climate changes [32,34]. In addition, Sohofi [35] studied the interrelationships between WFE resources and identified their effective variables and behavior patterns, and finally offered a qualitative model in order to illustrate the relationships between sources. Also, Simpson [36] assessed sustainable development goals for the security of water, food and energy resources based on the Nexus approach, and provided a conceptual framework in this regard. Mirzaei [37] examined the link between groundwater resources and food and energy to improve water security in Iran's agriculture sector. Chen [38] explored sustainable urban resources management using water-food-energy nexus approach in Taiwan considering economic growth. The results of this study identified water imports for the region. Schull [39] also analyzed SWAT[2]-based water resources management issues in the context of Nexus WFE model taking into account the population growth, economic growth and different scenarios of climate change. The model focuses on water quality in agriculture sector. Since these models have not been developed using System Dynamics (SD), temporal feedbacks between system elements were neglected and resources were analyzed at a particular time. Karnib [40] proposed a conceptual framework based on a technology-oriented approach for quantitative assessment of water–energy–food nexus and then discussed practical opportunities and considerations for WFE policy in Lebanon. A limited number of studies have developed policy-making models with the Nexus WFE-SD approach with the purpose of cross-sector integration. Akhtar [41] investigated the quality as well as the quantity of water resources changes taking into account the population, climate, economy, energy and food in Canada. This study indicated that dynamic system simulation and the feedback approach between subsystems provide the foundation for further studies.

Using the model of Sohofi [35], Melkonyan [42] modeled climate change as well as population, lifestyle and impacts on WFE resources accentuating food security in Armenia. The model focuses on the food sector at Nexus WFE including raw material production, preparation processes, food production, marketing and consumption. Ravar [8] presented the WFE-SD conceptual framework for upgrading basin-scale ecosystem services. The results revealed that water resources security and energy subsystem status in the basin are dependent to a large extent on the food sector. The researchers also confirmed the appropriate functioning of the model in demonstrating the impacts of water, agriculture and energy-related proposed policies for cross-sector coordination and planning. Water crisis in Iran is affected by three major factors of rapid growth and inappropriate pattern of population deployment, inefficient agriculture and mismanagement, and the hunger for development. Iran's water resources are seriously suffering from an inadequate structure of resource management. In the water sector, the diversity of interested parties in regulating water resources is naturally accompanied by conflict and rivalry [43]. Lack of comprehensive planning, sector and cross-sector decision-makings, and discrepancies on water resources policy-making have exacerbated the problem of water scarcity in the past two decades. In this study, using system dynamics theory, the resource sustainability variables in accordance with the Nexus WFE approach were identified and the dynamic sustainable water resources management model was applied with the intention of assisting managers and planners of the problem to understand and recognize the system behavior when confronted with organizational decisions.

2. Overview of the case study

Khuzestan Province contains parts of the three main basins of Karkheh, Grand Karun and Zohreh-Jarahi. Karkheh Basin with an

[2] Soil & Water Assessment Tool

area of 51.337 square kilometers and annual water volume of 6507.7 million cubic meters is located within the boundaries of 7 provinces, where Khuzestan Province bears 17% of the area of Karkheh basin equal to 8.683 square kilometers. Grand Karun Basin with an area of 67.257 square kilometers and annual water volume of 25015.4 million cubic meters is located within the boundaries of eight provinces, where Khuzestan Province contains 43 percent of its area equal to 28.871 square kilometers. Zohreh-Jarahi Basin bearing an area of 40.878 square kilometers and an annual water volume of 8.284 million cubic meters is located within the boundaries of five provinces, where Khuzestan Province contains 61 percent of its area equal to 24.832 square kilometers. Sections from three second-basin Karkheh, Grand Karun and Zohreh-Jarahi from first-basin Persian Gulf and Sea of Oman embrace the area of Khuzestan. The economic structure of Khuzestan Province has special conditions. The petroleum industry, oil included, accounting for about 78 percent of gross domestic product in the province has owned a major part of the economic activities [44]. Khuzestan produces about 80 percent of the country's crude oil and 16 percent of its gas, causing the province to have major investments in oil sector [45]. One of the main development opportunities of Khuzestan Province is the flow of a large part of the country's surface water, existence of permanent rivers with high discharge volume, having 9 huge dams already built or being under construction in different parts of the province, and their multipurpose utilization to develop agriculture, fishery, energy and drinking water supply sectors [46]. Other facilities in the province include significant soil and vegetation resources, suitable climates, the ability to plant and harvest crops three times in a large part of the province, and a considerable potential for developing agricultural activities and by-products in the field, which plays an important role in the development of the region and the entire country. Fig. 1 displays the characteristics of the study area.

3. Methodology

In this study, the system dynamics approach was used to model and simulate VENSIM DSS 6.4E software. This approach is helpful for social-learning and is a suitable method for modeling WFE nexus because it makes the dynamics between different systems comprehensible using dynamic feedback loops and nonlinear ordinary differential equations [8,47,48]. System Dynamics was first devised by Jay W. Forrester to help understand strategic issues in complicated dynamic systems[49]. Based on the Energy-Food-Water (WFE) Nexus and System Dynamics (SD) Approaches, the problem of sustainable water resources management was designed in three subsystems of water resources, food resources and energy resources. Fig. 2 shows the conceptual model and its subsystems.

In accordance with the conceptual framework and the system dynamics methodology, dynamic assumptions of the problem of water resource management integrity were designed. Fig. 3 illustrates the current research dynamic hypotheses. In the following sections, the modules of the WFE-SD model, which represent various sub-systems, are briefly described.

3.1. Nexus WFE system dynamics model

With formulation of dynamic hypotheses based on these assumptions, and inspirations from valid theories in the field of theoretical foundations of water resources management, the relationships between the variables of each subsystem together and also with other subsystems in the form of causal diagrams consisting of loops, positive and negative feedbacks were identified. Then, in order to construct the flow model, the trends of the variables were considered over time and the relationship between variables were formulated mathematically taking into account the trends and in accordance with the existing rules. Time series data gathering has been carried out based on the results by Iran Water Resources, Ministry of Agriculture Jihad, Statistical Center of Iran, Ministry of Energy and Ministry of Petroleum. The population is one direct factor that affects the supply and demand for water resources. Annual population growth rate has been calculated 0.01 using time series data (2011–2016) based on Eq. (1) and, the population function is based on Eq. (2) in the model [50,51].

$$P_{t+n} = P_t(1+r)^n \tag{1}$$

$$P(t) = \int_{t0}^{t} r \times P(t)dt, P(t0) = 4.76 \times 10^6 \tag{2}$$

Economic growth, especially the rapid growth of the gross domestic product (GDP)[3], can significantly influence water resources demand. The amount of the value added (VA) in the energy sector and that in the agriculture sector obtained from supply of water, food and energy sources play an important role in the gross domestic product and economic growth. The effect of the value-added growth of the energy sector and that of the food sector on economic growth have been considered according to Eqs. (3), (4), and (5) in the model so that the GDP logarithm represents the annual economic growth, and the value-added logarithms of the energy and agriculture sectors represent the rate of annual value-added growth of these sectors [52,53]. Regression coefficients of b1 and b2 have been calculated based on time series data (2011 to 2016) of economic growth, and the value-added growths in energy and agriculture. b1 denotes that of the agriculture sector value-added growth and b2 is the effect of the energy sector value-added growth on the amount of economic growth. Also, the effect of economic growth on water resources demand in the energy sector and the food sector has been taken into consideration.

$$logGDP = b_0 + b_1 \times \log VA_{Agricalturet} + b_2 \times \log VA_{Energyt} \tag{3}$$

$$Economicgrowth = \frac{GDP_t - GDP_{t-1}}{GDP_{t-1}} \tag{4}$$

$$VAgrowth = \frac{VA_t - VA_{t-1}}{VA_{t-1}} \tag{5}$$

Fig. 4 shows the flow diagram of the sustainable water resources management. The flow diagrams of each subsystem and their modeling details are discussed below.

3.2. Water resources subsystem

As shown in Fig. 5, the flow diagram of water resources subsystem has been designed to be consistent with the hydrological cycle of water so that surface water resources(SWR), stock variable and rainfall(W_{RF}), rate variables water return from renewable sources(W_{RS}), and water release from dams (W_{RD}) lead to an increase in the annual rate of surface water resources. On the other hand, evapotranspiration (W_{EV}), dams input volume (W_{ID}), surface water consumption (W_{SC})due to overall water demand, environmental need (W_{EN}) and influence soil (W_{IS}) have been considered to be the decreasing rates of available surface water resources. Eq. (6) representing the relation was used in the model.

$$SWR(t) = \int_{t0}^{t} (W_{RF} + W_{RS} + W_{RD} - W_{EV} - W_{ID} - W_{SC} - W_{IS} - W_{EN})dt \tag{6}$$

[3] Gross Domestic Product (GDP) is the monetary value of all finished goods and services made within during a year.

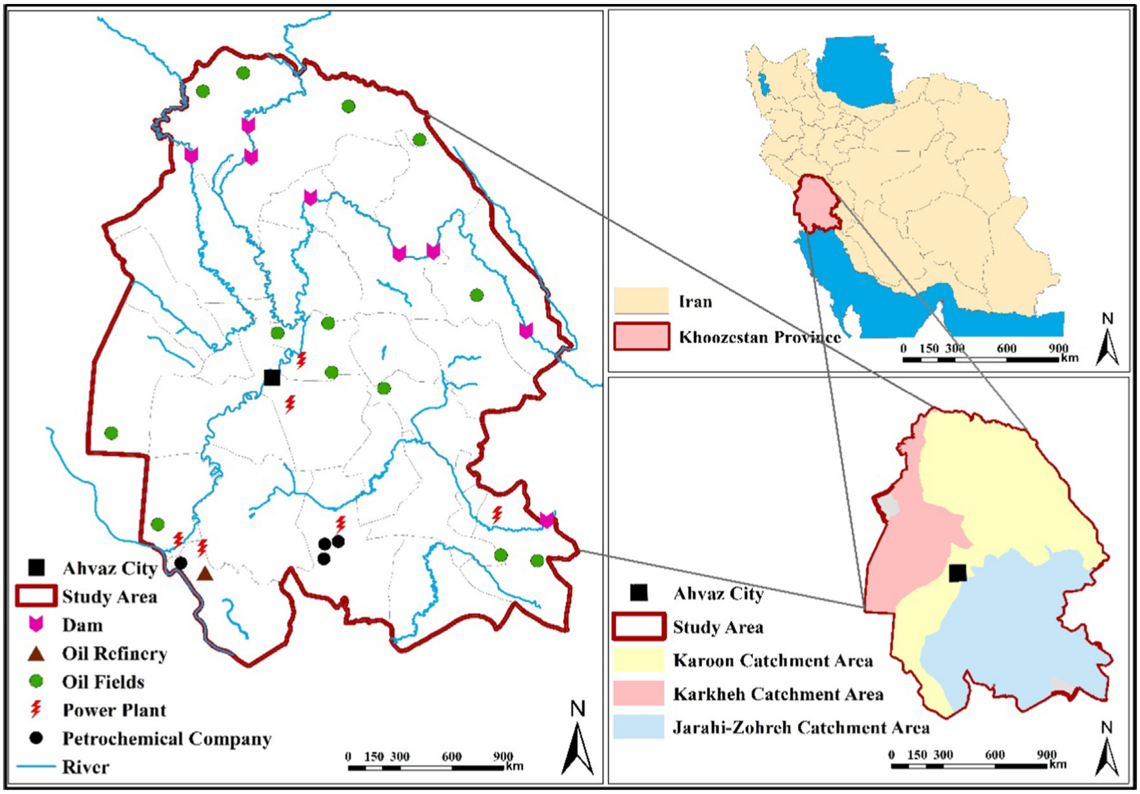

Fig.1. Case Study Location and Characteristics.

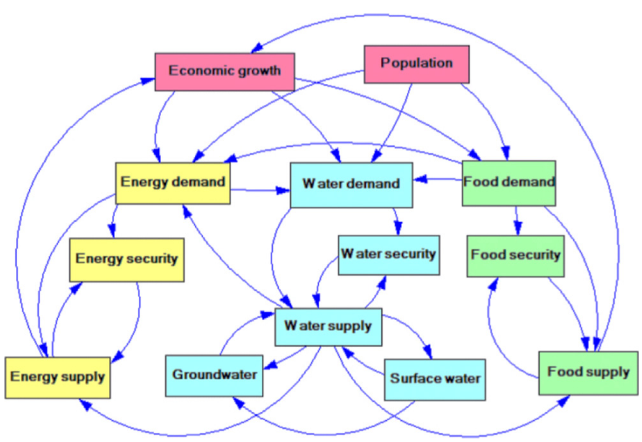

Fig.2. Conceptual Model of Sustainable Water Resources Management Based on the WFE Nexus.

The rainfall data are based on Thiessen polygon (TP) approach where $\bar{P}$ is the total precipitation in the basin. i denotes segmentation of the basin, P_i is the amount of rainfall in station i, and A_i represents the area of station i according to Eq. (7) in the model [54].

$$\bar{P} = \frac{\sum A_i \times P_i}{\sum A_i} \tag{7}$$

The total annual volume of dam water resources is based on the hydrological balance according to Eq. (8) [25,55]. ΔS_D is the total annual water volume of 6 main dams, I_{Di} and O_{Di} are the inflow and outflow to the reservoir for the dam i considered in the model.

$$\Delta S_D = \sum_{i=1}^{6} (I_{Di} - O_{Di}) \tag{8}$$

Another stock variable is groundwater resources(GWR), which is increased by the rate of influence on soil(W_{IS}), wastewater return(W_{WR}) and return from agriculture(W_{RA}), and is decreased by the rate of groundwater consumption (W_{GC}) due to the demand for groundwater and the volume that is intractable(W_{IG}) as in Eq. (9).

$$GWR(t) = \int_{t0}^{t} (W_{RA} + W_{WR} + W_{IS} - W_{IG} - W_{GC})dt \tag{9}$$

Water demand (W_{Demand}) is caused by the urban demand for water(WD_{water}), which is related to the population level and per capita water consumption, and is also caused by the energy sector demand for water(WD_{Energy}), the food demand for water(WD_{food}), and the industrial demand for water (WD_{Ind}) except the energy sector industries. The water supply(W_{Supply}) is provided through the accumulation of both surface water and groundwater resources, and the water security (WS) has been considered the difference between water supply and demand (Eqs. (10)–(12)). The values of the fixed variables of the model are presented in Table 2 and the mathematical formulation of the subsystem's main variables is shown in Appendix.

$$W_{Demand} = WD_{water} + WD_{Energy} + WD_{food} + WD_{Ind} \tag{10}$$

$$W_{Supply} = \mathrm{GWR} + \mathrm{SWR} \tag{11}$$

$$\mathrm{WS} = W_{Supply} - W_{Demand} \tag{12}$$

3.3. Food resources subsystem

Fig. 6 shows the flow diagram of the food resources subsystem. As it can be seen, the food supply comes from agricultural food sources, fisheries food sources, and livestock and poultry food

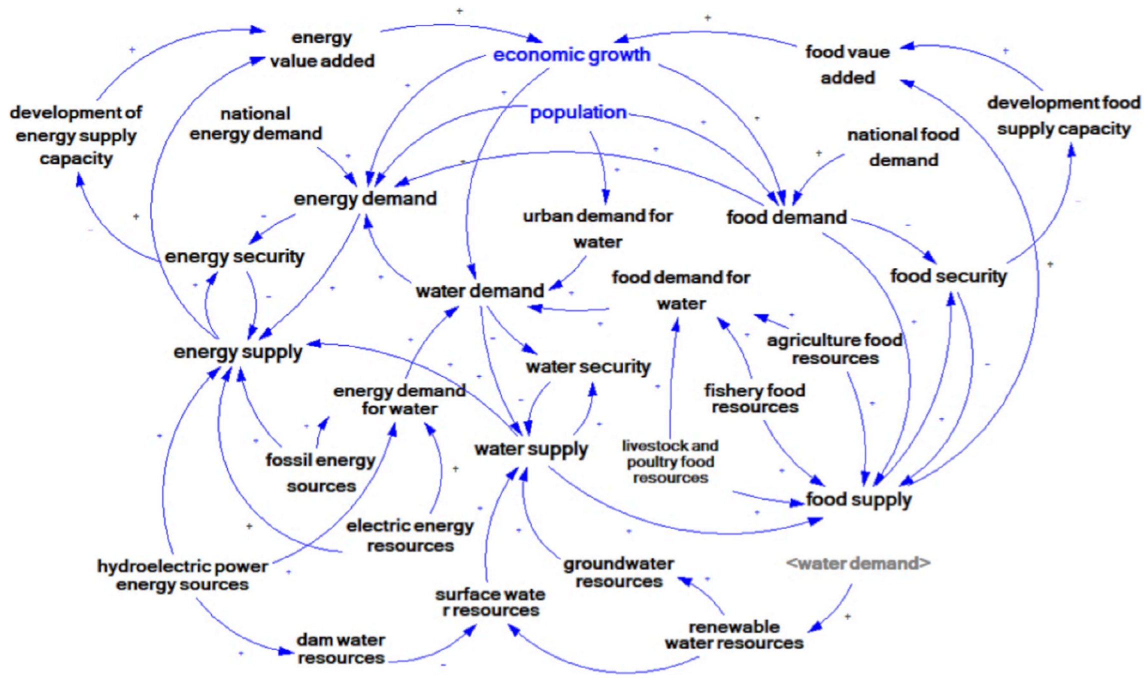

Fig.3. Dynamic Assumptions of Sustainable Water Resources Management with the Nexus Approach.

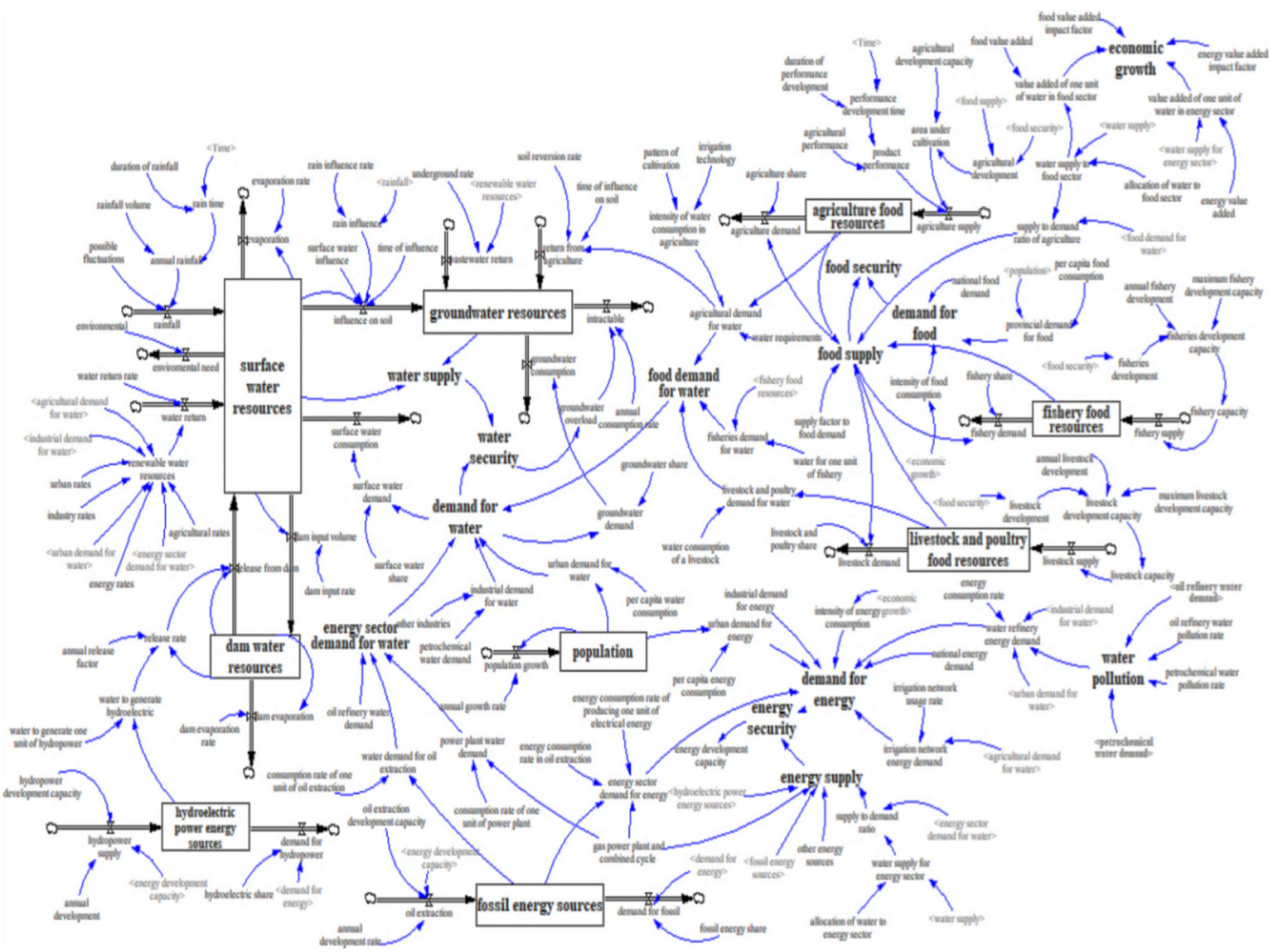

Fig.4. Flow Diagram of the Sustainable Water Resources Management Model.

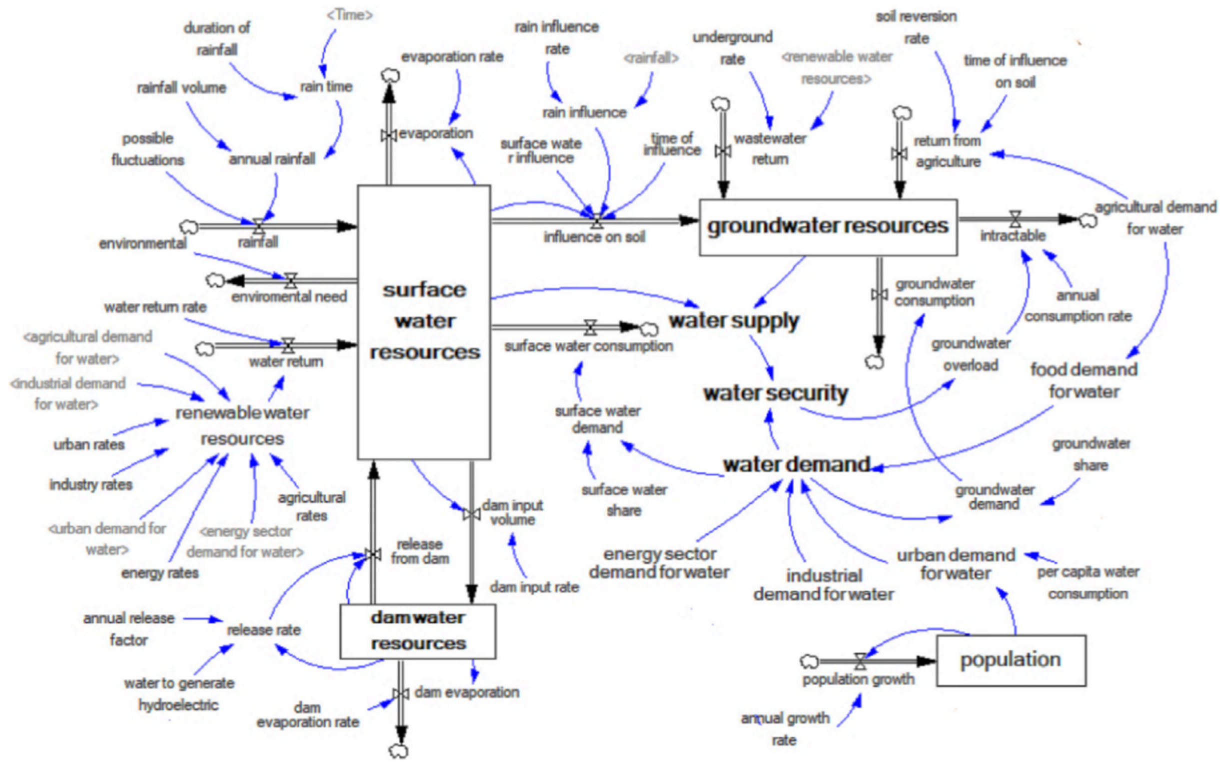

Fig.5. Flow Diagram of Water Resources Subsystem.

Table 2
Some of the Fixed Variables of water resource subsystem [44–46,56].

Variable	Value	Unit	Variable	Value	Unit
soil reversion rate	0.145	1/Year	evaporation rate	0.25	1/Year
surface water share	0.86	1/Year	groundwater share	0.14	1/Year
Environmental need	3e + 009	M3/year	per capita water consumption	171.87	M^3/Person

sources (Eq. (13)). Food demand is commensurate with the amount of domestic food demand that comes from population and per capita food consumption, national food demand and food intensity affected by economic development (Eq. (14)). The food security (FS) has been considered the difference between food supply and demand (Eq. (15)). The annual supply rate of the agriculture sector comes from the area under cultivation and product performance. Also, the annual supply rate of the fish and livestock and poultry sector is proportional to the capacity of these sectors. Food security, if imbalanced, is set by the size of agricultural development capacity, fishery development capacity, and livestock development capacity.

On the other hand, food demand for water stems from the water demand of all three sectors of agriculture, livestock and poultry, fisheries and the amount of water consumed per unit (Eq. (16)). The agricultural sector is the major demand for water, and the water demand in this sector is due to the amount of food production in agriculture sector, the water demand for crops, and the intensity of water consumption in the agriculture sector. The intensity of agricultural water consumption has been considered to be due to the pattern of cultivation and irrigation efficiency. The values of the fixed variables of the model are presented in Table 3 and the mathematical formulation of the subsystem's main variables is shown in Appendix.

$$F_{Supply} = F_{agri} + F_{livestock} + F_{fishery} \tag{13}$$

$$F_{demand} = (FD_{national} + FD_{provincial}) \times F_{intensity} \tag{14}$$

$$FS = F_{Supply} - F_{Demand} \tag{15}$$

$$WFD = F_{agri} \times WF_{agri} + F_{livestock} \times WF_{livestock} + F_{fishery} \times WF_{fishery} \tag{16}$$

3.4. Energy resources subsystem

As it can be seen in Fig. 7, the energy supply comes from fossil energy sources, hydroelectric power energy sources, power plants and other energy sources (Eq. (17)). Energy demand is commensurate with the amount of domestic energy demand that comes from population and per capita energy consumption(ED_{ur}), national energy demand(ED_{na}), energy sector demand(ED_{en}), industrial energy demand(ED_{ind}), water refinery energy demand(ED_{ref}), irrigation network energy demand (ED_{ir}) and the intensity of energy consumption affected by economic development (Eq. (18)).

$$E_{Supply} = E_{fossil} + E_{hydroelectricpower} + E_{powerplant} + E_{other} \tag{17}$$

$$E_{demand} = (ED_{ind} + ED_{na} + ED_{ur} + ED_{ir} + ED_{en} + ED_{ref}) \times E_{intensity} \tag{18}$$

The energy security (ES) has been considered the difference between energy supply and demand (Eq. (19)).The most important link between energy security and water security is the demand for the water in the extraction and production of oil and refineries. Water demand for energy sector, as can be seen in Eq. (20),

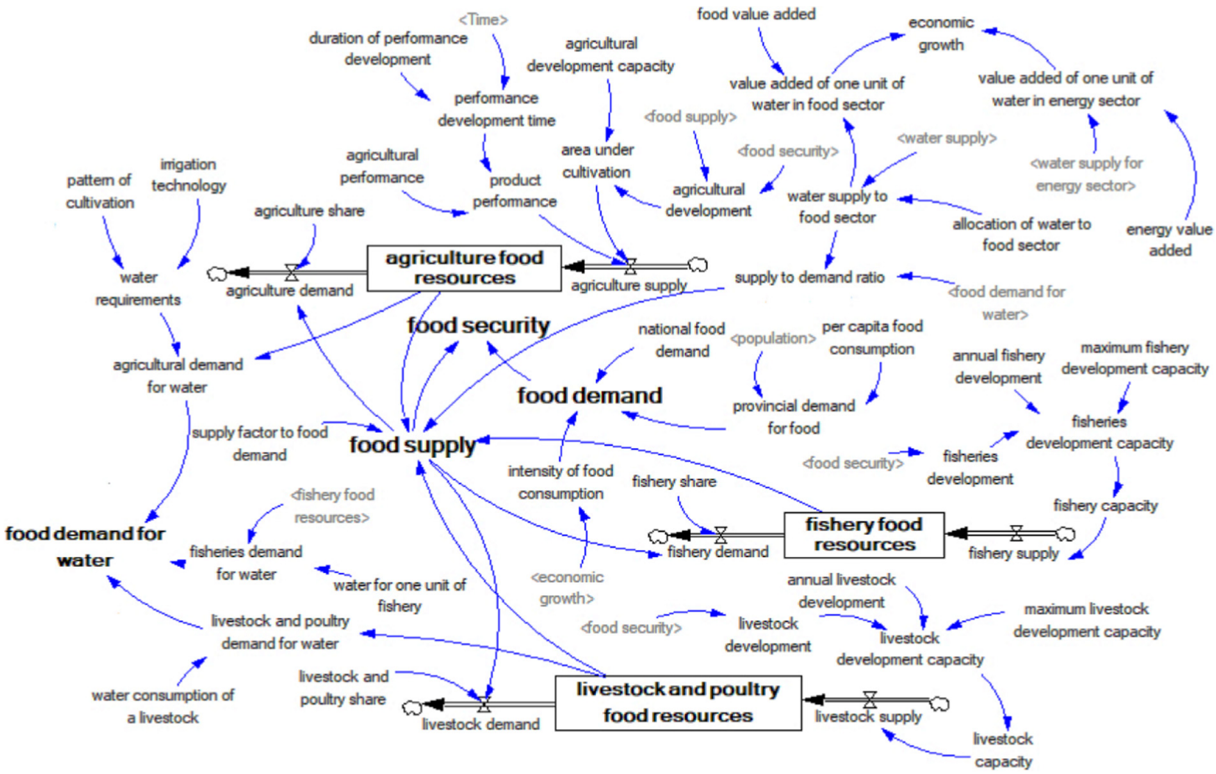

Fig.6. Flow Diagram of Food Resources Subsystem.

Table 3
Some of the Fixed Variables of food resources subsystem [44–46,56].

Variable	Value	Unit	Variable	Value	Unit
water requirements	146.25	M^3/Ton	allocation of water to food sector	0.9	Dmnl
water consumption of livestock	15	M^3/Kg	per capita food consumption	0.0418	Ton/Person

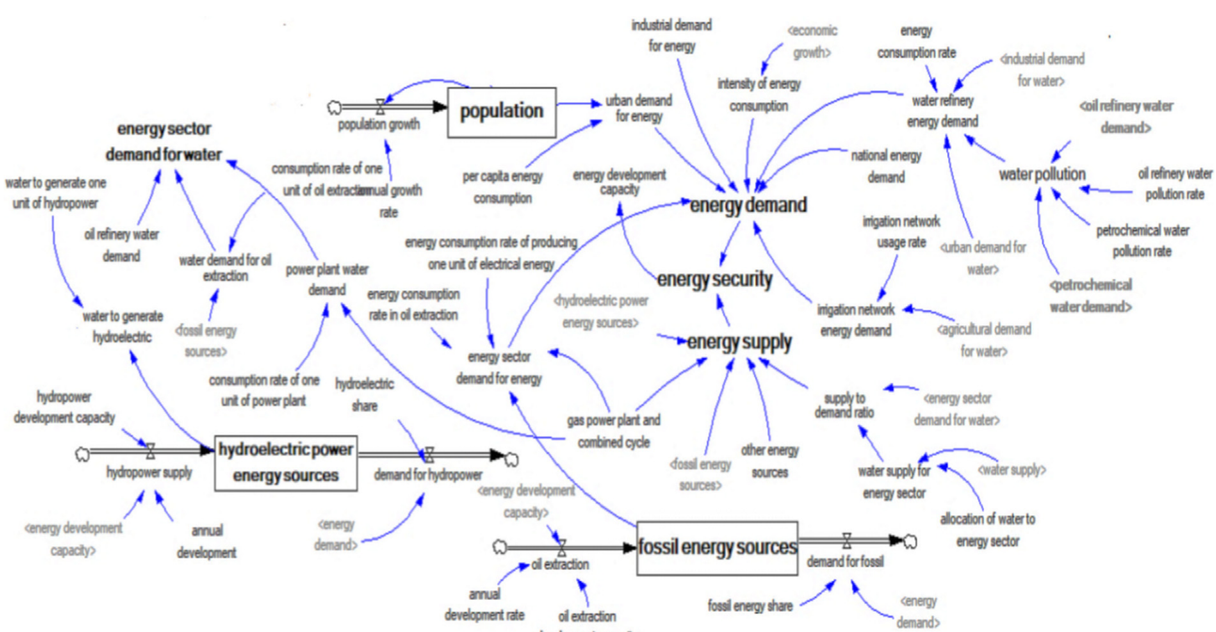

Fig.7. Flow Diagram of Energy Resources Subsystem.

includes the sources of energy produced at the power plants (E_{pp}), the amount of water consumed per unit of power plant(WD_{pp}), the resources of oil production (E_{oilext}) and the amount of water consumed per unit of oil extraction and production(WD_{oe}) as well as the consumed water in the oil refinery(WED_{oilref}). This sector is important in the sustainable management of water resources because it also includes water pollution. The values of the fixed variables of the model are presented in Table 4 and the mathematical formulation of the subsystem's main variables is shown in Appendix.

$$\mathrm{ES} = E_{Supply} - E_{Demand} \tag{19}$$

$$WED = E_{pp} \times WD_{pp} + E_{oilext} \times WD_{oe} + WED_{oilref} \tag{20}$$

3.5. Validation of dynamic model

This stage includes validating Nexus WFE-SD model. With the participation of experts and decision makers, all diagrams were discussed and validated; then the consultation finally resulted in a need to make several changes and adjustments to some of the variables of the model and their initial values. After ensuring that all the units and dimensions of the variables and equations were consistent, the flow model was simulated by VENSIM DSS 6.4E with annual time steps in a 20-year horizon. The results obtained from simulating different parts of the model show a good conformity with the historical trends. The period to be examined is from 2011 to 2016. Some of the simulated trends of the model have been compared with the historical data in Table 5 for validation. Root Mean Square Percentage Error (RMSPE) index has been calculated using Eq. (21) where, St is the simulated value, and At is the actual value.

$$\mathrm{RMSPE} = \sqrt{1/\mathrm{n}\sum_{\mathrm{t}=1}^{\mathrm{n}}\left(\frac{\mathrm{St}-\mathrm{At}}{\mathrm{At}}\right)^2} \tag{21}$$

Validation of the model including fitness tests, dimensionality test, limit condition test, and integral error test were performed, and the behavior of the model variables was approved by experts. The base year was considered to be as of 2016, and the simulation horizon is counted as 20 years. The simulation result of the main variables of interests including "Surface water resources", "Groundwater resources", "Food supply", "Water security", "Food security" and "Energy security" are respectively presented in Fig. 8.

4. Sensitivity analysis of dynamic model

Sensitivity analysis is used to determine how sensitive a model is to changes in the value of the parameters of the model, and also to indicate which parameter values are the leverage points of the model. Discovering that the system behavior greatly changes for a variation in a parameter value can identify a leverage point in the model-a parameter whose specific value can significantly influence the behavior mode of the system; thus, it can be manipulated as a scenario analysis to improve the model behavior. The software version of VENSIM DSS 6.4E supports Monte Carlo automatic sensitivity analysis. Monte Carlo simulation is known as multivariate sensitivity that performs sensitivity analysis automatically. In this case, hundreds or even thousands of simulations are performed for different values of the model constants in a specific domain, and the results are stored to analyze the behavior of the specified target variables. Here, to analyze the sensitivity of the model, 200 Monte Carlo simulations and the probability distribution of values are considered random uniform. With regards to the results obtained from Monte Carlo sensitivity analysis of all exogenous variables, taking into account the possible logical range of changes for each variable according to the planers, the target variables were not sensitive to most of them. Furthermore, the model showed a high sensitivity to the variables such as pattern of cultivation, irrigation technology and duration of performance development, which lead to be considered as leverage points of the model for the reason of policy making. The results of sensitivity analysis of some variables are displayed in Fig. 9.

5. Policy Scenarios, selection and implementation of changes

With the results of the model sensitivity analysis taken into consideration, and based on water resources crisis management

Table 4
Some of the Fixed Variables of the Model [44–46,56].

Variable	Value	Unit	Variable	Value	Unit
industrial demand for energy	2e+007	BOE[1]	other energy sources	100	BOE
consumption rate of one unit of oil extraction	3.6e-005	M^3/BOE	gas power plant and combined cycle	1298	BOE
irrigation network usage rate	0.0005	BOE/M^3	per capita energy consumption	26	BOE/Person
consumption rate of one unit of power plant	5	M^3/BOE	oil refinery water demand	2.7e + 007	M^3

[1] Barrel of oil equivalent. The barrel of oil equivalent (BOE) is a unit of energy based on the approximate energy released by burning one barrel (42 US gallons or 158.9873 L) of crude oil. One Kilowatt hour (KWh) is equal to 3,600,000 J (J) and one joule (J) is equal to $1.7060421187678 \cdot 10^{-10}$ barrel of oil equivalent (BOE).

Table 5
Comparison between (At) and (St) Behavior of Some Variables in the System [44–46].

RMSPE		2011	2012	2013	2014	2015	2016
annual rainfall (*Billion M* ^{3}),	At	17.33	29.9	26.7	21.4	31.9	20.8
RMSPE = 0.014	St	17.34	28.9	26.7	20.2	30.9	21.3
agriculture food resources (Million Ton), RMSPE = 0.043	At	13.20	13.5	13.9	14.5	14.5	15.2
	St	13	14	14.7	15.2	15.6	15.9
product performance (Ton/Hectare), RMSPE = 0.01	At	13.2	13.7	14.3	15.1	15.5	15.7
	St	13	14	14.7	15.1	15.4	15.7
agricultural demand for water (Billion M ^{3}), RMSPE = 0.021	At	11.96	12.5	12.9	13.3	14.2	14.5
	St	11.84	12.7	13.4	13.8	14.1	14.4
fossil energy sources (Billion BOE), RMSPE = 0.032	At	800	825	830	850	880	1000
	St	800	827	857	880	905	930

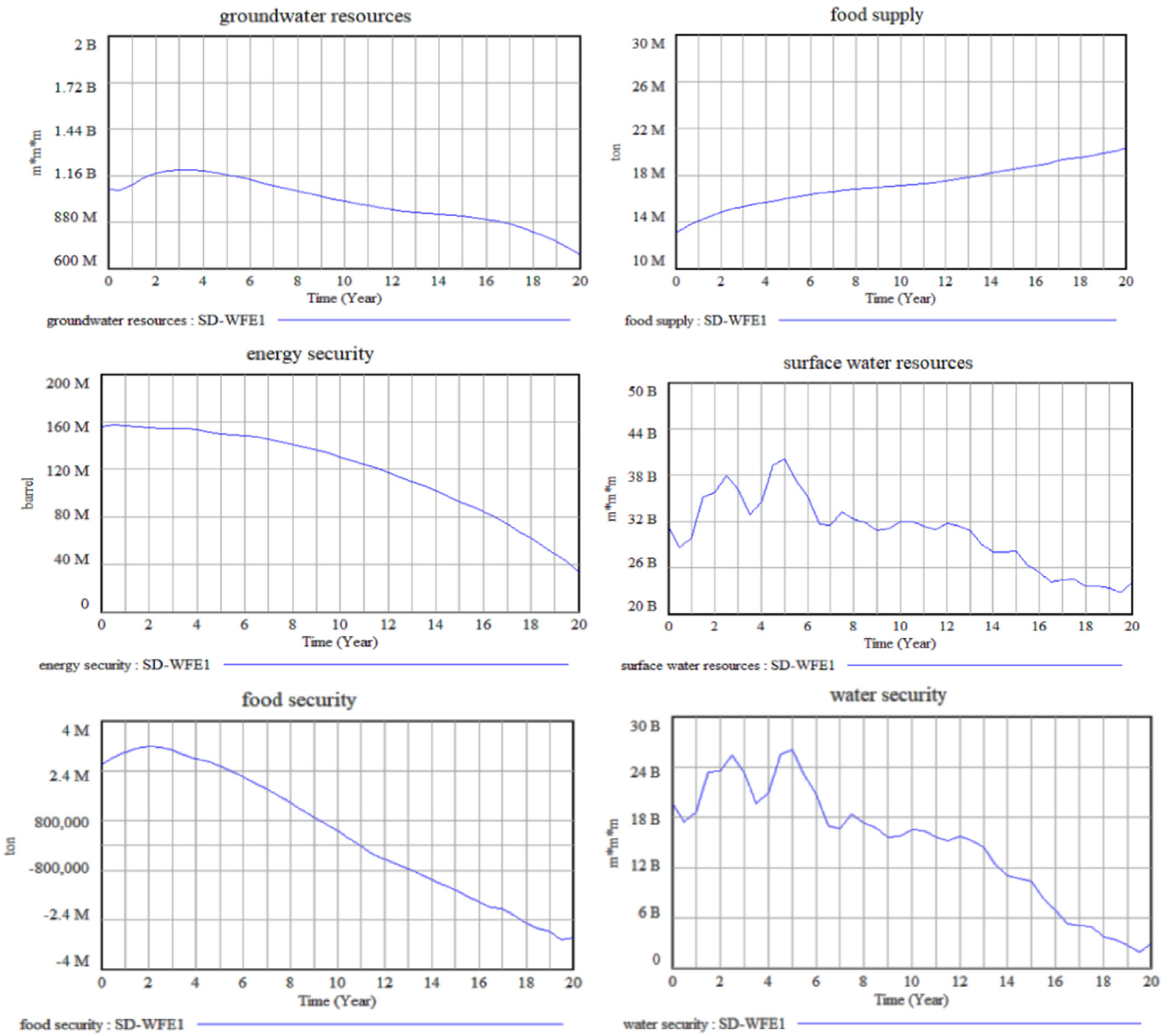

Fig.8. Simulation Result of the Main Variables of the Model.

strategies, sustainable water resources management policies were identified in four categories of identification strategies using expert opinion, and in accordance with the existing studies and planning in the units involved in the problem. Then, with application of each policy in the model, the results were measured on the target variables including water security, food security and energy security. These policies are outlined below.

5.1. Policy 1: Water resource supply management scenario

These solutions are designed to focus on water supply management and seek to increase the available water resources. By reducing the development capacity of the hydroelectric power plant from 0.023% to 0.018% per year, the volume of water stored behind the dams in the area is decreased and the available water resources are increased. In addition, by improving the rate of renewable water in the energy, industry and urban water sectors, the status of water supplies will be improved taking into account the feasible and implementable changes.

5.2. Policy 2: Water resources demand management scenario

This set of solutions is designed to focus on water demand management. Since agricultural sector is the largest water applicant, this policy focuses on increasing irrigation efficiency as well as modifying the pattern of cultivation. According to the report by Agricultural Jihad of Khuzestan Province, irrigation efficiency differences are present in the surface irrigation method and the pressure irrigation method, and currently, 30% of the irrigation network lands are under pressure. Therefore, if the irrigation network is developed, at least 16% of the total irrigation requirement will be reduced by the area under cultivation of the dominant crops. Table 6 shows the irrigation information with the two methods of surface irrigation and pressure irrigation for the dominant crops. On the other hand, considering the changes in the pattern of cultivation in some crops such as rice, corn and tomato, taking into account the regional conditions and considering the food security of the country, the amount of water required by the agricultural sector will be up to 10% efficient [44].

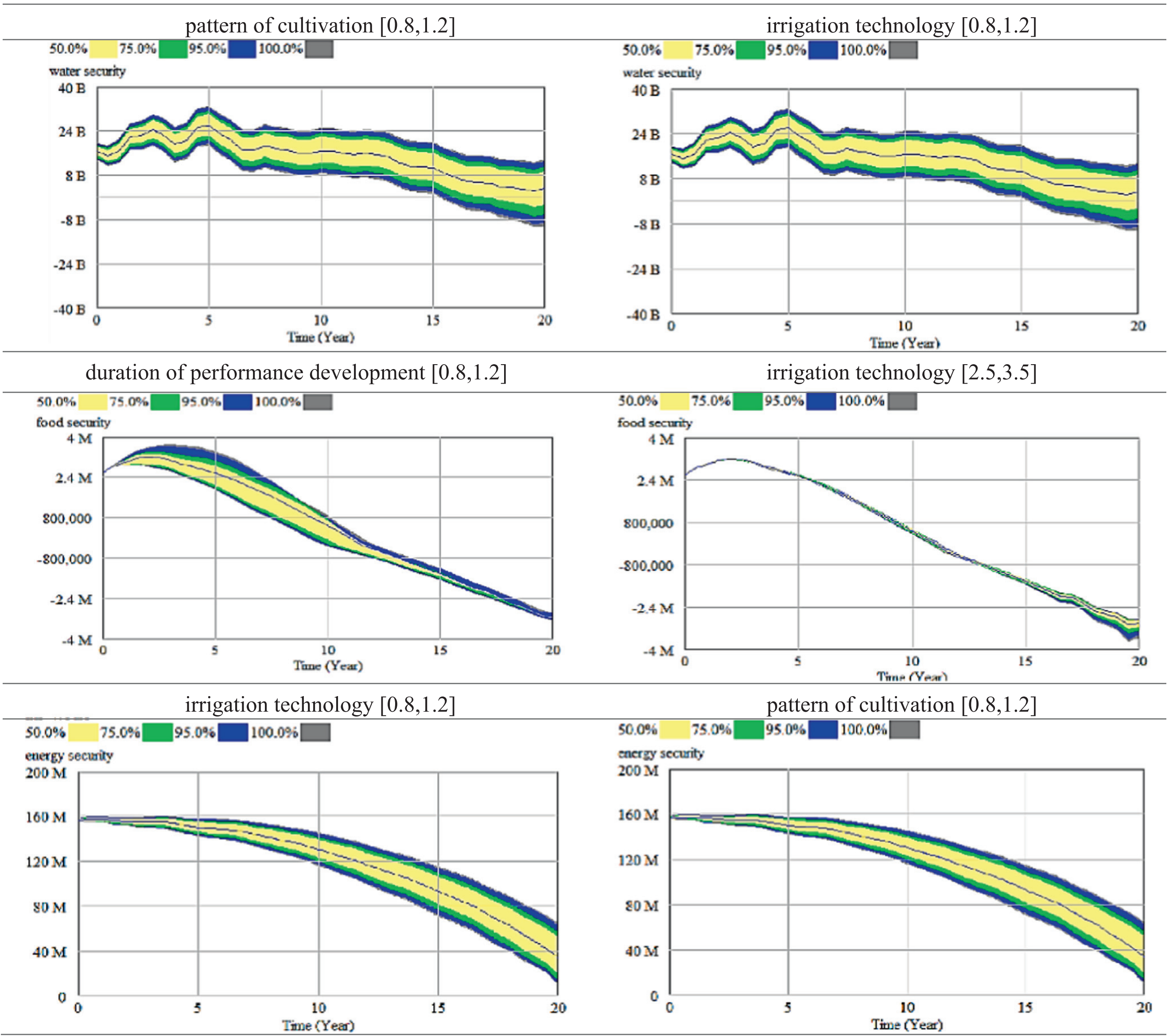

Fig.9. Monte Carlo Sensitivity Analysis of some exogenous variables in the system.

Table 6
Irrigation information for the dominant agricultural crops (surface irrigation and pressure irrigation methods) [44].

Agricultural corps	Surface irrigation efficiency (percent)	Water consumption (m^3/hectare)	Pressure irrigation efficiency (percent)	Water consumption (m^3/hectare)
wheat	40	5100	65	3825
barley	40	4100	65	3375
tomatoes	45	6000	85	3600
dates	48	17,500	85	11,025

5.3. Policy 3: Food resource management scenario

This category of solutions focuses on food resources supply and demand management. According to the FAO and the Agricultural Jihad Organization in Iran, the severity of food losses is on average 12 percent in the production and pre-harvest stages, 25 percent in the relocation, storage, processing and distribution stages, and 10 percent in consumption [56]. If losses are identified, managed and reduced at various stages, our supply of food resources will be increased in reality. Based on this policy, the production loss management rate was 12% the region's dominant crops including wheat and barley taken into account. We will achieve sustainable resource security solutions if we reduce waste to at least 6%, reduce food consumption by 5% per capita by acculturating and modifying food consumption patterns, and also improve crop yields by 5% through seed breeding, fertilizers and new agriculture methods.

5.4. Policy 4: Energy demand management scenario

Taking into account the basin under study, fossil energy resources extraction, the refinery industries of petroleum products, and petrochemical industries have the highest demand for water. In addition to the intensity of the water consumed by these industries, water pollution is one of the challenges ahead. The hunger for development in Khuzestan basin is focused on exploiting more of the oil and gas extraction resources as well as on the development of related industries. Due to the high value added of these industries and their role in the economic growth and development of the country, the devastating effects of these industries are neglected. This policy seeks to achieve sustainability through reducing the industries water pollution rate in order to reduce water purification energy, and consequently to reduce the energy consumption in thermal power plants and the refining and petrochemical industries. Table 7 summarizes the proposed policies, and Fig. 10 shows the results of the proposed policies on the main variables.

After applying each of the policies separately to the model and also applying the combined policies, the key variables of the model were studied, and the results were compared. Studies have shown that a combination of policy 02 and policy 03 is the best strategy for improving the security of water, food and energy resources for a simulated 20-year horizon. Fig. 11 shows the results of the combined policy of water demand management and food resource management.

Table 7
Identified policies regarding the sustainable water resources management.

Scenarios	Changes applied in the dynamic model	Rate of change
Policy 01: Water Supply Management	Reducing the development of hydroelectric capacity to reduce the volume of water stored behind dams	0.5% reduction
	Increasing the rate of renewable urban water	10% increase
	Increasing the rate of renewable water in the energy sector	5% increase
	Increasing the rate of renewable water in the industry	5% increase
Policy 02: Water Demand Management	Modifying the pattern of cultivation	10% improvement
	Developing the irrigation technology	16% increase
Policy 03: food resource Management	Reducing food demand by reducing food losses	6% reduction
	Increasing food supply by reducing agricultural losses	5% increase
	Improving the performance of agricultural products	5% improvement
Policy 04: Energy Demand Management	Reducing the energy consumption rate at the power plant	5% reduction
	Reducing the energy consumption rates in the oil refinery industry	10% reduction
	Reducing the energy consumption rate in the petrochemical industry	10% reduction
	Reducing water pollution rate in the petrochemical industry	15% reduction
	Decreasing the refinery water pollution rate	5% reduction

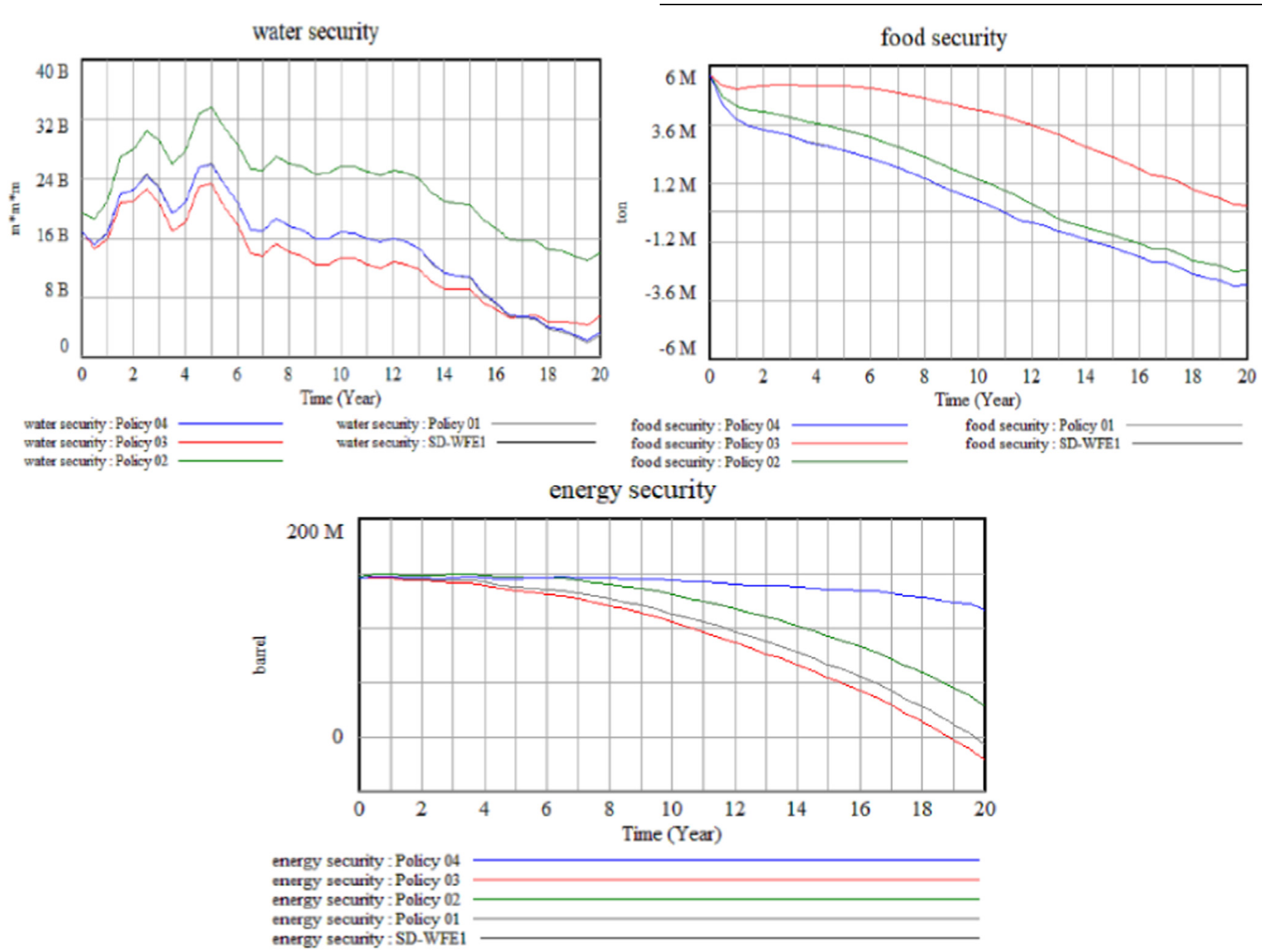

Fig.10. Behavior of Key Variables by Policies Changes.

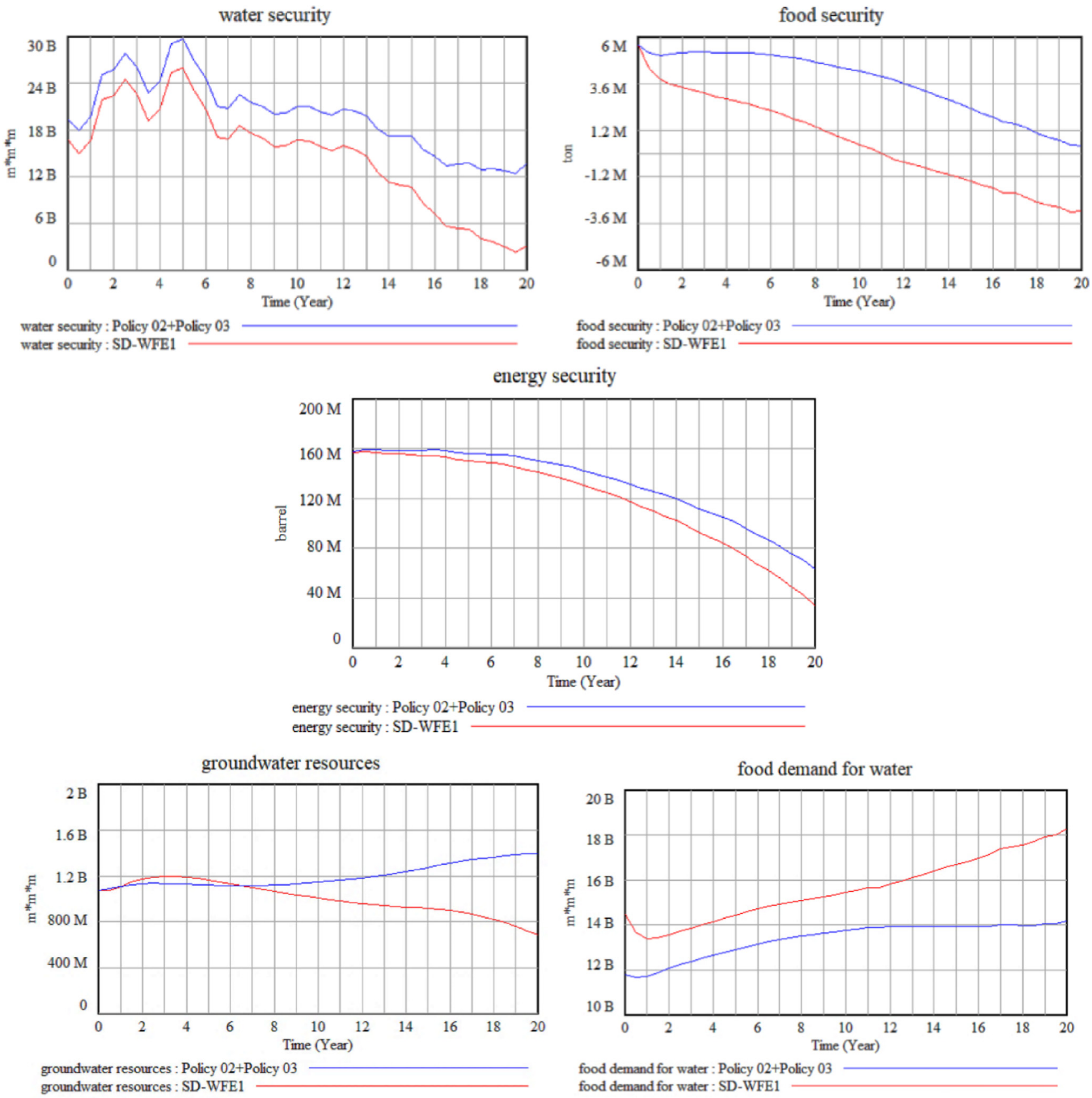

Fig.11. Behavior of Key Variables with the Combined Policy of Policy 02 and Policy 03.

6. Conclusions and suggestions

Complex problem planning in all areas requires deep identification of the problem to determine its root causes; otherwise, some policies and programs will be developed that are not only unable to solve the existing problems, but will also add to the existing problems by expending the limited resources and facilities without properly having the required analysis. In this study, the model of sustainable water resources management based on water, food and energy approach was investigated, and the system behavior in problem position was simulated over a 20-year horizon. Considering leverage points including the pattern of cultivation, irrigation technology and duration of performance development obtained from the results of the Mont Carlo sensitivity analysis of the WFE-SD model and the views of experts and decision makers, the most appropriate systemic and applicable solutions were determined in line with resource sustainability policies including water supply management, water demand management, food resources management and energy demand management. By taking into account the effects of these strategies on the behavior of the model objective variables in the long run, the following strategies will lead to sustainable water resources management:

- Developing an irrigation and drainage network of agricultural lands to increase irrigation efficiency by 16%
- Modifying the cultivation pattern by 10%, taking into account the regional climate and food security of the country and cultivation with less water demand

- Managing food loss before, during and after the harvest to reduce it by 6%
- Modifying food consumption patterns in order to manage consumption losses, and reduce the food demand by 5%
- Developing the agricultural product performance by 5% using seed modification, fertilizer application and new cultivation methods

In order to develop the model in future research efforts, the following is recommended: addition of virtual water variables, development of the cultivation pattern modification variable in the region with regards to the standard plant water demand and climatic conditions, recyclability of urban sewage water with respect to grey water footprint, details about migration and land use, the quality of water, and the impact of new and renewable energies on resource security.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Main Mathematical Relationships of Water Resources Subsystem (*Unit*)

water supply = groundwater resources + surface water resources, *Units: M* ^{3}

Water demand= (industrial demand for water + energy sector demand for water + urban demand for water + food demand for water), *Units: M* ^{3}

water security = water supply- water demand, *Units: M* ^{3}

surface water resources = INTEG (rainfall + water return + release from dam – evaporation - dam input volume - surface water consumption - influence on soil - environmental need), *Units: M* ^{3}

groundwater resources = INTEG (return from agriculture + w astewater return + influence on soil – intractable - groundwater consumption), *Units: M* ^{3}

dam water resources = INTEG (dam input volume - dam evaporation - release from dam), *Units: M* ^{3}

population = INTEG (population growth), *Units: person*

rainfall = annual rainfall × possible fluctuations, *Units: M* ^{3}*/Year*

influence on soil = SMOOTH(surface water resources × surface water influence + rain influence, time of influence), Units: *M* ^{3}*/Year*

evaporation = evaporation rate × surface water resources, *Units: M* ^{3}*/Year*

wastewater return = renewable water resources × underground rate, *Units: M* ^{3}*/Year*

return from agriculture = SMOOTH(agricultural demand for water × soil reversion rate × 0.6, time of influence on soil), *Units: M* ^{3}*/Year*

release from dam = release rate × dam water resources, *Units: M* ^{3}*/Year*

dam input volume = surface water resources × dam input rate, *Units: M* ^{3}*/Year*

release rate = IF THEN ELSE(dam water resources>=water to generate hydroelectric, (dam water resources - water to generate hydroelectric)/dam water resources , 0) × annual release factor, *Units: 1/Year*

renewable water resources= (industrial demand for water × industry rates)+(energy sector demand for water × energy rates)+(agricultural demand for water × agricultural rates)+(urban demand for water × urban rates), *Units: M* ^{3}*/Year*

Main Mathematical Relationships of Food Resources Subsystem (*Unit*)

food supply = IF THEN ELSE(supply to demand ratio of agriculture>=1, fishery food resources + agriculture food resources + livestock food resources, (supply to demand ratio of food × supply factor to food demand ×(fishery food resources + agriculture food resources + livestock and poultry food resources))), *Units: ton*

Food demand = (national food demand + provincial demand for food) × intensity of food consumption, *Units: ton*

food security = food supply- food demand, *Units: ton*

agriculture food resources = INTEG (agriculture supply-agriculture demand), *Units: ton*

fishery food resources = INTEG (fishery supply-fishery demand) , *Units: ton*

livestock and poultry food resources = INTEG (livestock supply-livestock demand) , *Units: ton*

agriculture supply = area under cultivation × product performance, *Units: ton/Year*

agriculture demand = food supply × agriculture share, *Units: ton/Year*

food demand for water = fisheries demand for water + livestock and poultry demand for water + agricul tural demand for water, *Units: M* ^{3}

agriculture supply = area under cultivation × product performance, Units: ton/Year

product performance = agricultural performance(performance development time), *Units: ton/hectare*

agricultural demand for water = intensity of water consumption in agriculture × agriculture food resources × water requirements, *Units: M* ^{3}

intensity of water consumption in agriculture = pattern of cultivation × irrigation technology, *Units: Dmnl*

agricultural development = IF THEN ELSE(food security<=0, −1 × food security/food supply , 0), *Units: Dmnl*

value added of one unit of water in food sector = food value added/water supply to food sector, *Units: Rial/ M* ^{3}

fisheries development capacity = IF THEN ELSE(fisheries development<=maximum fishery development capacity, fisheries development , maximum fishery development capacity) × annual fishery development, *Units: ton/Year*

livestock development capacity = IF THEN ELSE(livestock development<=maximum livestock development capacity, livestock development, maximum livestock development capacity) × annual livestock development, *Units: ton/Year*

Main Mathematical Relationships of Energy Subsystem (*Unit*)

energy supply = IF THEN ELSE(supply to demand ratio>=1, other energy sources + hydroelectric power energy sources + fossil energy sources + gas power plant and combined cycle , (supply to demand ratio × (other energy sources + hydroelectric power energy sources + fossil energy sources + gas power plant and combined cycle)), *Units: BOE*

supply to demand ratio = water supply for energy sector / energy sector demand for water, *Units: Dmnl*

energy demand =(energy sector demand for energy + water

(*continued on next page*)

refinery energy demand + urban demand for energy + irrigation network energy demand + industrial demand for energy + national energy demand) × intensity of energy consumption , *Units: BOE*

energy security = energy supply- energy demand, *Units: BOE*

energy development capacity = IF THEN ELSE(energy security>=0, 0 , energy security × -1), *Units: BOE*

fossil energy sources = INTEG (oil extraction-demand for fossil), *Units: BOE*

oil extraction = oil extraction development capacity + energy development capacity × annual development rate, *Units: BOE /Year*

demand for fossil = demand for energy × fossil energy share, Units: *BOE /Year*

hydroelectric power energy sources = INTEG (hydropower supply–demand for hydropower), *Units: BOE*

hydropower supply = hydropower development capacity +(energy development capacity × annual development), *Units: BOE /Year*

demand for hydropower = demand for energy × hydroelectric share, *Units: BOE /Year*

energy sector demand for water= (power plant water demand + water demand for oil extraction + oil refinery water demand), *Units:* M^3

energy sector demand for energy = gas power plant and combined cycle × energy consumption rate of producing one unit of electrical energy + fossil energy sources × energy consumption rate in oil extraction, *Units: BOE*

water pollution= (oil refinery water demand × oil refinery water pollution rate)+(petrochemical water demand × petrochemical water pollution rate), *Units:* M^3

water refinery energy demand=(urban demand for water + water pollution + industrial demand for water) × energy consumption rate, *Units: BOE*

irrigation network energy demand = agricultural demand for water × irrigation network usage rate, *Units: BOE*

urban demand for energy = population × per capita energy consumption, *Units: BOE*

energy sector demand for energy = gas power plant and combined cycle × energy consumption rate of producing one unit of electrical energy + fossil energy sources × energy consumption rate in oil extraction, *Units: BOE*

power plant water demand = gas power plant and combined cycle × consumption rate of one unit of power plant, *Units:* M^3

water demand for oil extraction = fossil energy sources × consumption rate of one unit of oil extraction, *Units:* M^3

References

[1] UNESCO. Nature-based solutions for water. The United Nations World Water Development Report; 2018.
[2] UNESCO. The United Nations world water development report 2015: water for a sustainable world - UNESCO Digital Library. UN-Water 2015. https://unesdoc.unesco.org/ark:/48223/pf0000231823 [accessed March 19, 2020].
[3] FAO. Energy-smart food for people and climate. Issue Paper. RomeFood Agric Organ United Nations 2011:66.
[4] International Energy Agency [IEA]. World Energy Outlook 2010 Edition 2010:1–735.
[5] Hoff H. Understanding the nexus: Background paper for the Bonn2011 Nexus Conference: the water, energy and food security nexus. Nexus Conf. water, energy food Secur. nexus. Stock. Environ. Institute, Bonn, 2011.
[6] UNESCAP. The Status of the Water-Food-Energy Security Nexus in Asia and the Pacific region. United Nations Econ Soc Com Asia Pacific 2013:44.
[7] Al-Saidi M, Elagib NA. Towards understanding the integrative approach of the water, energy and food nexus. Sci Total Environ 2017;574:1131–9. doi: https://doi.org/10.1016/j.scitotenv.2016.09.046.
[8] Ravar Z, Zahraie B, Sharifinejad A, Gozini H, Jafari S. System dynamics modeling for assessment of water–food–energy resources security and nexus in Gavkhuni basin in Iran. Ecol Indic 2020;108:. doi: https://doi.org/10.1016/j.ecolind.2019.105682105682.
[9] Bazilian M, Rogner H, Howells M, Hermann S, Arent D, Gielen D, et al. Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy 2011;39:7896–906. doi: https://doi.org/10.1016/j.enpol.2011.09.039.
[10] Rost S, Gerten D, Hoff H, Lucht W, Falkenmark M, Rockström J. Global potential to increase crop production through water management in rainfed agriculture. Environ Res Lett 2009;4:. doi: https://doi.org/10.1088/1748-9326/4/4/044002044002.
[11] Atherton JT. A system dynamics approach to water resources and food production in the Gambia. 2013.
[12] Huang F, Liu Z, Ridoutt BG, Huang J, Li B. China's water for food under growing water scarcity. Food Secur 2015;7:933–49. doi: https://doi.org/10.1007/s12571-015-0494-1.
[13] Zhang X, Guo Q, Shen X, Yu S, Qiu G. Water quality, agriculture and food safety in China: Current situation, trends, interdependencies, and management. J Integr Agric 2015;14:2365–79. doi: https://doi.org/10.1016/S2095-3119(15)61128-5.
[14] Yang H, Reichert P, Abbaspour KC, Zehnder AJB. A Water Resources Threshold and Its Implications for Food Security. Environ Sci Technol 2003;37:3048–54. doi: https://doi.org/10.1021/es0263689.
[15] Zhao J, Liu W, Deng H. The potential role of virtual water in solving water scarcity and food security problems in China. Int J Sustain Dev World Ecol 2005;12:419–28. doi: https://doi.org/10.1080/13504500509469651.
[16] El-Gafy K, System I. Dynamic Model for Crop Production, Water Footprint, and Virtual Water Nexus. Water Resour Manag 2014;28:4467–90. doi: https://doi.org/10.1007/s11269-014-0667-2.
[17] Du B, Zhen L, de Groot R, Long X, Cao X, Wu R, et al. Changing Food Consumption Patterns and Impact on Water Resources in the Fragile Grassland of Northern China. Sustainability 2015;7:5628–47. doi: https://doi.org/10.3390/su7055628.
[18] Li X. Understanding the water-energy nexus: A case study of Ningxia. Master Thesis Sustain Dev Uppsala Univ 2014;204:30.
[19] Jobbins G, Kalpakian J, Chriyaa A, Legrouri A, El Mzouri EH. To what end? Drip irrigation and the water–energy–food nexus in Morocco. Int J Water Resour Dev 2015;31:393–406. doi: https://doi.org/10.1080/07900627.2015.1020146.
[20] Khiareddine A, Ben Salah C, Rekioua D, Mimouni MF. Sizing methodology for hybrid photovoltaic /wind/ hydrogen/battery integrated to energy management strategy for pumping system. Energy 2018;153:743–62. doi: https://doi.org/10.1016/j.energy.2018.04.073.
[21] Pacetti T, Lombardi L, Federici G. Water–energy Nexus: a case of biogas production from energy crops evaluated by Water Footprint and Life Cycle Assessment (LCA) methods. J Clean Prod 2015;101:278–91. doi: https://doi.org/10.1016/j.jclepro.2015.03.084.
[22] Cabrera E, Pardo MA, Cobacho R, Cabrera E. Energy Audit of Water Networks. J Water Resour Plan Manag 2010;136:669–77. doi: https://doi.org/10.1061/(ASCE)WR.1943-5452.0000077.
[23] Plappally AK, Lienhard VJH. Energy requirements for water production, treatment, end use, reclamation, and disposal. Renew Sustain Energy Rev 2012;16:4818–48. doi: https://doi.org/10.1016/j.rser.2012.05.022.
[24] Wang S, Cao T, Chen B. Water–energy Nexus in China's Electric Power System. Energy Procedia 2017;105:3972–7. doi: https://doi.org/10.1016/j.egypro.2017.03.828.
[25] Zhuang Y. A system dynamics approach to integrated water and energy resources management. Grad Sch Theses Diss 2014:1–217.
[26] Khalifehei K, Azizyan G, Gualtieri C. Analyzing the Performance of Wave-Energy Generator Systems (SSG) for the Southern Coasts of Iran, in the Persian Gulf and Oman Sea. Energies 2018;11:3209. doi: https://doi.org/10.3390/en11113209.
[27] Liu L, Hejazi M, Patel P, Kyle P, Davies E, Zhou Y, et al. Water demands for electricity generation in the U.S.: Modeling different scenarios for the water–energy nexus. Technol Forecast Soc Change 2015;94:318–34. doi: https://doi.org/10.1016/j.techfore.2014.11.004.
[28] Nogueira Vilanova MR, Perrella Balestieri JA. Exploring the water-energy nexus in Brazil: The electricity use for water supply. Energy 2015;85:415–32. doi: https://doi.org/10.1016/j.energy.2015.03.083.
[29] Samavatean N, Rafiee S, Mobli H. An Analysis of Energy Use and Estimation of a Mechanization Index of Garlic Production in Iran. J Agric Sci 2011;3:198–205. doi: https://doi.org/10.5539/jas.v3n2p198.
[30] Tokgoz S, Zhang W, Msangi S, Bhandary P. Biofuels and the Future of Food: Competition and Complementarities. Agriculture 2012;2:414–35. doi: https://doi.org/10.3390/agriculture2040414.
[31] Smith JU, Fischer A, Hallett PD, Homans HY, Smith P, Abdul-Salam Y, et al. Sustainable use of organic resources for bioenergy, food and water provision in rural Sub-Saharan Africa. Renew Sustain Energy Rev 2015;50:903–17. doi: https://doi.org/10.1016/j.rser.2015.04.071.
[32] Bellezoni RA, Sharma D, Villela AA, Pereira Junior AO. Water-energy-food nexus of sugarcane ethanol production in the state of Goiás, Brazil: An analysis with regional input-output matrix. Biomass Bioenergy 2018;115:108–19. doi: https://doi.org/10.1016/j.biombioe.2018.04.017.

[33] Mayor B, López-Gunn E, Villarroya FI, Montero E. Application of a water–energy–food nexus framework for the Duero river basin in Spain. Water Int 2015;40:791–808. doi: https://doi.org/10.1080/02508060.2015.1071512.
[34] Howells M, Hermann S, Welsch M, Bazilian M, Segerström R, Alfstad T, et al. Integrated analysis of climate change, land-use, energy and water strategies. Nat Clim Chang 2013;3:621–6. doi: https://doi.org/10.1038/nclimate1789.
[35] Sohofi A, Melkonyan A, Karl C, Krumme K. System Archetypes in the Conceptualization Phase of Water-Energy-Food Nexus Modeling. Proc 34th Int Conf Syst Dyn Soc 2016;34:1–16.
[36] Simpson GB, Jewitt GPW. The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review. Front Environ Sci 2019;7:1–9. doi: https://doi.org/10.3389/fenvs.2019.00008.
[37] Mirzaei A, Saghafian B, Mirchi A, Madani K. The Groundwater-Energy-Food Nexus in Iran's Agricultural Sector: Implications for Water Security. Water 2019;11:1835. doi: https://doi.org/10.3390/w11091835.
[38] Chen I-C, Wang Y-H, Lin W, Ma H. Assessing the risk of the food-energy-water nexus of urban metabolism: A case study of Kinmen Island. Taiwan. Ecol Indic 2020;110:. doi: https://doi.org/10.1016/j.ecolind.2019.105861105861.
[39] Schull VZ, Daher B, Gitau MW, Mehan S, Flanagan DC. Analyzing FEW nexus modeling tools for water resources decision-making and management applications. Food Bioprod Process 2020;119:108–24. doi: https://doi.org/10.1016/j.fbp.2019.10.011.
[40] Karnib A, Alameh A. Technology-oriented approach to quantitative assessment of water–energy–food nexus. Int J Energy Water Resour 2020:1–9. doi: https://doi.org/10.1007/s42108-020-00061-w.
[41] Akhtar MK, Wibe J, Simonovic SP, MacGee J. Integrated assessment model of society-biosphere-climate-economy-energy system. Environ Model Softw 2013;49:1–21. doi: https://doi.org/10.1016/j.envsoft.2013.07.006.
[42] Melkonyan A, Krumme K, Gruchmann T, De La Torre G. Sustainability assessment and climate change resilience in food production and supply. Energy Procedia 2017;123:131–8. doi: https://doi.org/10.1016/j.egypro.2017.07.236.
[43] Madani K. Water management in Iran: what is causing the looming crisis?. J Environ Stud Sci 2014;4:315–28. doi: https://doi.org/10.1007/s13412-014-0182-z.
[44] . Nat Resour Report/Provincial Water Resour Khuzastan Prov Prep Stud 2014.
[45] National Iranian South Oilfields Company. Retrieved from Natl Iran South Oilfields Co 2020. https://nisoc.ir/HomePage.aspx?TabID=3546&Site=nisoc&Lang=fa-IR [accessed March 19, 2020].
[46] Iran Water Resources Management Company, Profile of Iranian dams 2019. http://daminfo.wrm.ir/fa/dam/tabularview.
[47] Hassanzadeh E, Elshorbagy A, Wheater H, Gober P. Managing water in complex systems: An integrated water resources model for Saskatchewan. Canada. Environ Model Softw 2014;58:12–26. doi: https://doi.org/10.1016/j.envsoft.2014.03.015.
[48] Feng M, Liu P, Li Z, Zhang J, Liu D, Xiong L. Modeling the nexus across water supply, power generation and environment systems using the system dynamics approach: Hehuang Region. China. J Hydrol 2016;543:344–59. doi: https://doi.org/10.1016/j.jhydrol.2016.10.011.
[49] Sterman J. System Dynamics: systems thinking and modeling for a complex world 2002.
[50] Yang J, Lei K, Khu S, Meng W. Assessment of Water Resources Carrying Capacity for Sustainable Development Based on a System Dynamics Model: A Case Study of Tieling City China. Water Resour Manag 2015;29:885–99. doi: https://doi.org/10.1007/s11269-014-0849-y.
[51] Sun Y, Liu N, Shang J, Zhang J. Sustainable utilization of water resources in China: A system dynamics model. J Clean Prod 2017;142:613–25. doi: https://doi.org/10.1016/j.jclepro.2016.07.110.
[52] Yousef Mehnat far, Hamed S, Bijan BS. The Impact of Economic Sectors' Value Added on Economic Growth: The case of The Iranian Provinces During 4th Development Plan. J Macroecon (JOURNAL Econ Sci 2015;10.
[53] Abdouli M, Omri A. Exploring the Nexus Among FDI Inflows, Environmental Quality, Human Capital, and Economic Growth in the Mediterranean Region. J Knowl Econ 2020. doi: https://doi.org/10.1007/s13132-020-00641-5.
[54] Nesru M, Nagaraj MK, Shetty A. Assessment of consumption and availability of water in the upper Omo-Gibe basin. Ethiopia. Arab J Geosci 2020;13:13. doi: https://doi.org/10.1007/s12517-019-4897-8.
[55] Habets F, Molénat J, Carluer N, Douez O, Leenhardt D. The cumulative impacts of small reservoirs on hydrology: A review. Sci Total Environ 2018;643:850–67. doi: https://doi.org/10.1016/j.scitotenv.2018.06.188.
[56] Mirmajidi hashtjin A, Famil momen R, Godarzi F. Post harvest loss reduction Most important strategic approch in enhancement of food security. 2016.