J. Agr. Sci. Tech. (2022) Vol. 24(3): 707-722

Determination of Optimal Irrigation Water Supply Scenario for Karkheh Dam to Prevent Drainage Problems of Dashte Abbas Plain Using System Dynamics Approach

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ABSTRACT

Dashte Abbas is one of the fertile plains of the Ilam Province situated in the southwest of Iran, where water resources are scarce, and often the quality of water is not suitable for agricultural uses. To solve the problem of water scarcity, the Karkheh-Dashte Abbas inter-basin water transfer project started operation in 2008. The objective of this study was to investigate the effects of different agricultural water management scenarios on the environmental and economic conditions in the Dashte Abbas using the System Dynamics (SD) approach. The conceptual model was considered based on five sub-models, including water demand, water supply, environmental stresses, environment, and water economics. The evaluated water transfer scenarios were allocation of 160, 170, 180, 200 Million Cubic Meters (MCM) water transferred from the Karkheh Dam and 90, 80, 70, and 60 MCM annual groundwater withdrawal from the aquifer, respectively. The results showed that in all scenarios, water transfer increased groundwater level, decreased groundwater quality, reduced soil aeration and drainage, increased salinity of root zone and, consequently, reduced agricultural production in the plain. The results of the SD model demonstrate that the need for drainage is reduced with increasing groundwater consumption. The alternative cropping systems with higher water requirements, including forage crops and sugar beet, may be helpful to reduce drainage problems and to prevent construction of an underground drainage system. The results also confirmed that with the implementation of the first water allocation scenario (allocation of annual 160 MCM surface water transfer and annual 90 MCM of groundwater withdrawal) and cultivation of higher water requirement crops can reduce the rise in groundwater level and drainage problems. In these conditions, the water table remains almost constant at a depth of 10 meters.

Keywords: Conceptual model, Water economics, VENSIM software.

INTRODUCTION

In addition to the System Dynamics (SD) approach, other modeling methods such as Bayesian Networks (BNs), Artificial Neural Networks (ANNs), and Genetic Algorithms (GAs) are proposed to model the complex environments such as water resource planning. Bayesian networks are powerful tools for simulating the random nature of physical phenomena. The primary purpose of constructing BNs is to estimate the probable invisible events (Henriksen *et al.*, 2007). The most important advantage of using BNs is that they can be used to model the components of systems with limited, incomplete, accidental, uncertain, or unstructured information. However, BNs cannot be used to understand the dynamics of different changing states and flows (relative to time) of the system boundaries. Therefore, creating greater insight into the use of the SD

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approach regarding analyzing biophysical problems and their integration with social and economic aspects to deduce policy implications of natural resource management decisions seem to be required (Khan *et al*., 2009).

Susnik *et al*. (2012) applied the SD approach to develop a comprehensive water resource plan and assess water scarcity. Saysel *et al*. (2002) simulated the cropping pattern, crop rate, and agricultural pollution through the SD approach in a region in the south of Turkey. After evaluating the model (behavior test, limit test, and structure test) and verifying the model of scenarios, these researchers finally assessed the strategy and policy of the region. Their results showed that the policies adopted in managing the mentioned projects would have severe environmental damages. Subsequently, the researchers presented the proposed retrofitted policies.

Nozari (2009) used SD analysis to manage the exploitation of agricultural drainage. The dynamic model presented in this study was used to study different methods of managing saline drainage produced in Amir Kabir Agro-Industrial and Industrial Complex (one of the seven Sugar Development Companies in Ahwaz) after validation. The results of this study showed that the proposed dynamic model could be useful in designing and managing drainage systems.

Khan *et al*. (2009) simulated the daily water-yield at a rice farm and interactions between shallow groundwater and water balance in the farm using the SD through VENSIM software. The results showed that the modified model was able to simulate evaporation from the soil surface, deep percolation, runoff, up-flow, and groundwater level. The mentioned model is also able to simulate the effects of different irrigation management scenarios on developing the efficiency improvement strategies for using the irrigation water and controlling the water table, controlling the soil salinity in the upstream lands, and reducing the downstream drainage costs.

Alizadeh *et al*. (2014) developed a comprehensive model to investigate the long-term effects of Tehran's sewage on Varamin Plain agricultural uses using system dynamic modeling (VarSim). The results of the assessment of the scenarios indicated that maintaining the existing conditions would destroy the groundwater aquifer of Varamin Plain by 2041.

Xi and Poh (2013) used system dynamics for sustainable water resources management in Singapore. The results showed that groundwater resource storage and basin management alone would not lead to sustainable water resources.

Hosseini and Bagheri (2013) modeled the water resources system of Mashhad Plain using the SD method. The results showed that the effect of decreasing or increasing all factors is not equal to the sum of the effect of decreasing or increasing each one of them on the stability of the region. Besides, changing the cropping pattern to the proposed cropping (wheat cultivation with 3000 $m^3.ha^{-1}$ water requirement) can be effective in improving the status of water resources in Mashhad Plain as a superior policy.

Nazari (2013) developed the Qazvin Irrigation Network using the SD technique of economic and physical water productivity model. The results showed that the cropping pattern has a significant impact on the aquifer status and it is necessary to consider educational and supervisory strategies to modify the cropping pattern to improve water productivity and maintain water resources sustainability. Giordano *et al*. (2012) introduced a dynamic modeling system to analyze the conflicts in groundwater management. The results showed that, although the design and implementation of groundwater protection policies were significant, efforts to solve the water management problem due to unpredictable effects make it worse in many cases. Agricultural systems and their environmental effects, like many other environmental problems, constitute complex systems, whose study requires systemic approaches capable of explicitly managing the temporal dimension, sustainability conditions, uncertainty and externalities (Nozari *et al*, 2014, Liu *et al*, 2015). Xi and Poe (2013) used the dynamics of the system for the sustainable management of Singapore's water resources. The results showed that the storage of groundwater resources and catchment management alone did not lead to the sustainability of water resources.

Evaluation of the previous studies indicates that the SD method is a suitable method to study the complexity of water resource management, especially agricultural water management. Accordingly, we aimed to use this method to investigate the cause of the water table rise in Dashte Abbas in the Ilam Province to provide a management support model.

MATERIALS AND METHODS

Study Area

Dashte Abbas is located in the southwest of Iran between the north latitude (32° 15' to 32° 30') and the eastern longitude (40° 47' to 48° 10'). This plain is located in the Karkheh River Basin in Ilam Province. The average height of the plain is 164 m. The net area is 16,450 hectares. Figure 1 shows the study area of Dashte Abbas, which is one of the most important agricultural plains in the Ilam Province (IRWCBS, 2013).

The study area is located in the southeast of Ilam Province, Iran. The climate of the area is classified into arid and semi-arid regions based on different climatic classifications (IRWCBS, 2014). The climatic parameters in the study area are presented in Table 1.

Development of the System Dynamics Model

In this study, Vensim software was used for simulation and development of the dynamic model.

Vensim provides a fully integrated simulation system to conceptualize, document, simulate, analyze, and optimize models of dynamic systems (Khan *et al*., 2009). SD modeling was carried out in three main stages: (i) Drawing causal loop diagrams, (ii) Modeling the interrelationship among variables, and (iii) Testing the model and developing the final model.

The conceptual framework and some of the key variables of the model are presented in Figure 2.

The conceptual model was considered based on five sub-models, including water demand (agriculture, industry, and domestic), water supply (dam and wells), environmental stresses (salinity and water stress), water economics (energy costs, investment costs, wells deepening, revenues, etc.), and the environment (water balance, solute in the soil and groundwater). According to the conventional method in system dynamics, the key variables are classified as internal and external variables. Internal variables include the variables that are inside the system boundary, which affect the system and are affected by the system (such as cropping pattern, allocated water, efficiencies). External variables include variables that are outside the system boundary and affect the system but are not affected by the system (such as agricultural products prices, crop costs, and climate).

The Causal Loop Diagram

In this stage, the variables and the relationship among variables are determined in the causal loop diagrams. In SD modelling, the causal loop diagrams represent the major feedback mechanisms, which reinforce (positive feedback loop is represented by ‘+’) or counteract (negative feedback loop is represented by ‘–’) a given change in a system variable (Sterman 2000). A sample of the feedbacks existing in groundwater utilization is presented in Figure 3. In the loop, with increasing the area of high water consuming crops, the

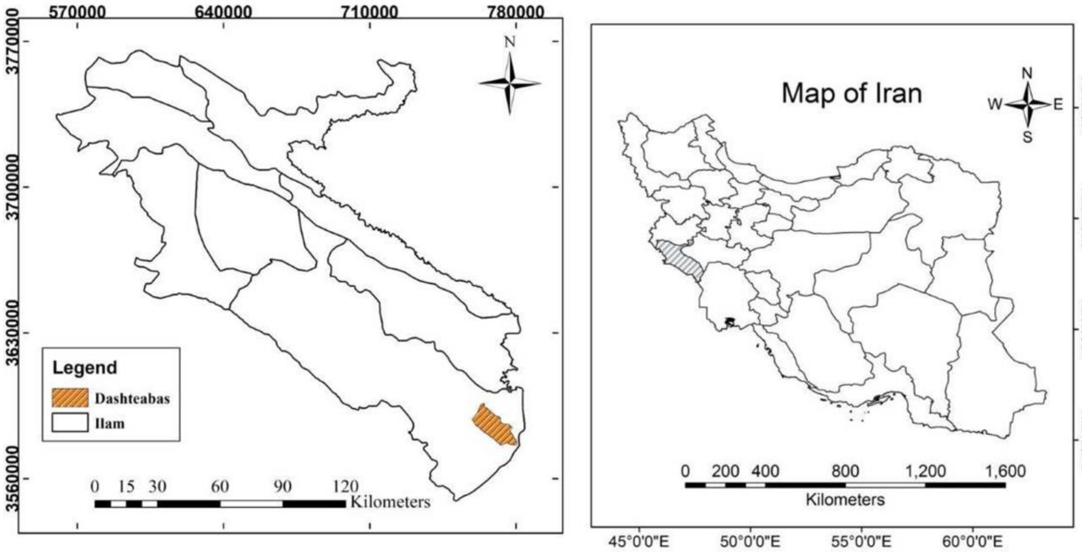

Figure 1. The geographic location of the study area of Dashte Abbas in Ilam Province.

Table 1. Summary of climatic parameters in the study area (IRWCBS, 2014).

	Variable	Months												Annually
		Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Des	Nov	Oct	
Temperature (°C)	Absolute maximum	5.48	0.52	6.53	8.50	6.47	0.42	0.36	0.29	5.28	2.30	0.35	5.43	6.53
	Maximum average	0.43	8.45	4.45	9.41	4.35	3.28	2.22	5.18	7.17	3.21	7.28	0.37	1.32
	Average	6.33	3.36	9.35	6.32	3.27	0.21	8.15	7.12	1.12	2.15	2.21	5.28	4.24
	Maximum average	2.24	9.26	4.26	4.23	1.19	8.13	3.9	9.6	6.6	0.9	7.13	9.19	6.16
	Absolute minimum	0.10	5.16	0.19	0.16	0.10	0.3	0.2-	0.4-	0.9-	0.2-	0.1	0.6	0.9-
Humidity	Maximum average	37	35	34	38	52	68	77	83	86	80	64	45	58
	Monthly average	26	24	24	27	36	49	58	64	68	62	47	32	43
	Maximum average	15	14	14	15	21	30	38	45	51	45	31	20	28
Precipitation	Monthly average	0.0	2.0	1.0	4.0	3.12	8.28	9.36	4.47	6.52	6.49	7.21	2.0	0.252
	Monthly percentage	0.0	1.0	0.0	1.0	9.4	4.11	7.14	8.18	9.20	7.19	6.8	8.0	0.100
Average wind speed (m s)		61.1	78.1	99.1	19.2	16.2	90.1	63.1	42.1	25.1	17.1	23.1	38.1	64.1
Potential ETO* (mm)		0.233	7.263	4.275	4.248	5.221	1.165	0.116	8.81	1.71	5.91	2.152	1.213	9.2132
Evaporation from the Pan (mm)		1.475	4.564	5.589	6.531	4.386	2.229	2.145	0.97	0.83	1.110	9.204	7.351	0.3768

groundwater withdrawal will increase and as a result of this increase, the water and energy costs will increase. With increasing the water and energy costs, crop costs and agricultural revenue will increase and decrease, respectively. With decrease in the agricultural revenue, the area of high water consuming crops will be decreased (the balancing or negative loop).

Simulation of Relationships between Variables.

In this section, the most important relationships in modeling, the key, and auxiliary variables, as well as the summary of the model

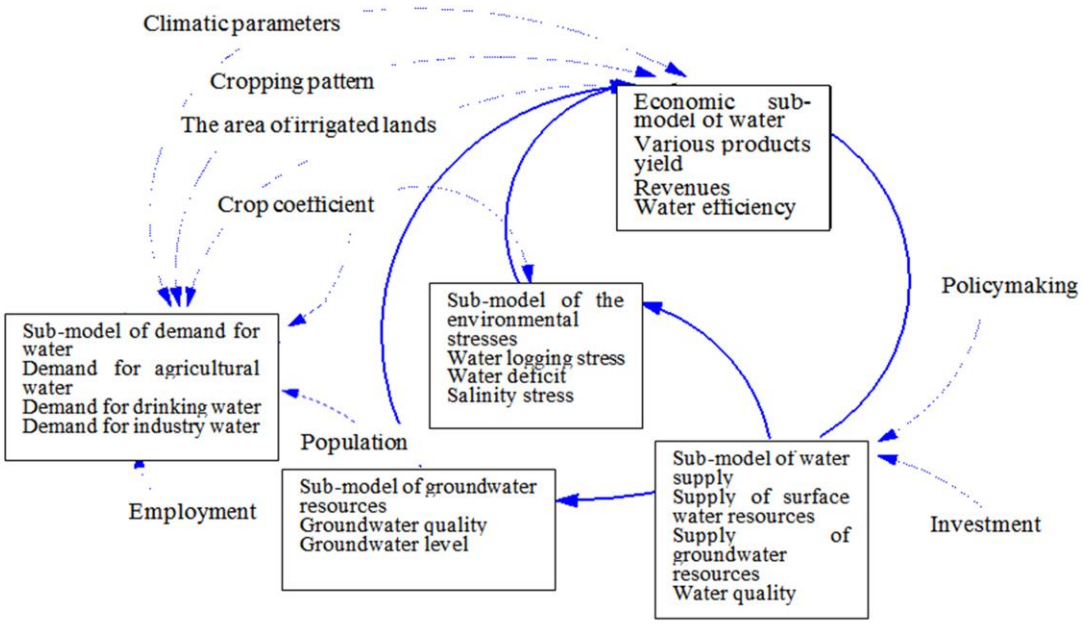

Figure 2. The conceptual framework of water resources management in Dashte Abbas.

state structure including, sub-models and sub-sections, are presented.

Water Demand Sub-Model

Water demand in the agricultural sector was calculated according to the net water requirement of the cropping pattern, cropping pattern scenarios, water stress coefficients (Ks), irrigation efficiency (application efficiency dependent on soil type and irrigation system, transmission efficiency, and distribution depending on water resource). The most important variables in the farm subsystem are potential evapotranspiration of the plant, actual evapotranspiration of the plant, effective rainfall, net irrigation requirement, deficit water coefficient, irrigation efficiency, applied irrigation depth in each period, total irrigation water during growing season, available water of the soil, drought stress coefficient, evaporation from the soil surface, and yield.

The Potential Evapotranspiration of the crop (ETcP), actual Evapotranspiration of the crop (ETc) and drought stress coefficient Ks were estimated by Equations 1 to 3. The value of Ks parameter was calculated according to soil type, plant type, irrigation interval, and irrigation system using water balance in the soil (Doorenbos *et al*. 1979).

$$ET_{cp} = ET_o \times K_c \qquad (1)$$

$$ET_c = K_S \times ET_{cp} \qquad (2)$$

Where, Dr is the moisture Depletion of the root development zone and the Moisture Allowed Discharge (MAD), TAW is Total Available Water and RAW is Rapidly Available Eater.

According to the water balance in the soil and variables such as Total Available Water (TAW) in the soil, infiltration water (irrigation and effective precipitation), drainage, plant evapotranspiration, and evaporation from soil surface are calculated (Equation 4).

$$K_S = \begin{cases} 1, & Dr \le RAW \\ \dfrac{TAW - Dr}{TAW - RAW} = \dfrac{TAW - Dr}{TAW(1 - MAD)}, & RAW < Dr \le TAW \end{cases} \qquad (3)$$

$$\text{Soil AW[crop,soil]} = \int_{t_0}^{t_n} (\text{Inflow rate[crop]- depletion[crop,soil]})dt + \text{Soil AW[crop,soil]}(t_0) \qquad (4)$$

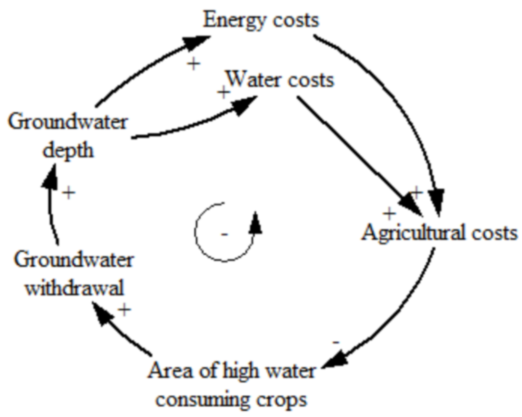

Figure 3. Causal Loop Diagram (CLD).

Inflows include effective precipitation, water stress coefficient, applied irrigation water, and outflows include evaporation from the soil surface and deep percolation.

The method proposed by FAO (2012) was used to calculate the evaporation from the soil surface. In this method, the Kr coefficient is calculated according to the Evaporation of the soil surface (Es) and relative Water availability in the soil (Wrel) (Equation 5), and based on this coefficient and potential evapotranspiration (Equation 6). In this method, an exponential correlation between Kr coefficient and relative Water availability in the upper layer of soil (Wrel) is used to consider the reduction of hydraulic conductivity due to the reduction of water availability in the soil.

$$0 \leq \mathrm{Kr} = \frac{\exp^{f_k W_{rel}-1}}{\exp^{f_k}-1} \leq 1 \quad (5)$$

The value of 4 is recommended for fk coefficient (Ritchie, 1972).

$$Es = Kr \times ETo \quad (6)$$

The water requirement of the cropping pattern (In) was calculated through Equation (7):

$$In = ET_C - Pe \quad (7)$$

Where, Pe (effective Precipitation) was calculated using the FAO Equation.

$$\begin{aligned} &Pe = 0.6 \times P - 10 && if\ P <= 70mm \\ &Pe = 0.8 \times P - 240 && if\ P > 70mm \end{aligned} \quad (8)$$

Where, P was considered as the decade time unit rainfall of Dehloran Station (mm).

The gross Irrigation requirement (Ig) was calculated from Equation (9).

$$Ig = \frac{In}{Ei} \times DI \quad (9)$$

Where, Ei is the irrigationE and DI is the Deficit Irrigation coefficient.

The irrigation efficiency of the Dashte Abbas Irrigation Network was considered based on the second phase of irrigation and drainage network of Dashte Abbas (transmission, distribution, and application efficiency as much as 90, 85, and 65% respectively; IRWCBS, 2013).

Water Supply Subsystem from Karkheh Dam

The only resource of water supply for the water supply network is Karkheh Dam. The daily data of water supply from Karkheh Dam were obtained from the Ilam Regional Water Company's primary research office from 2007 to 2015 (IRWCBS, 2015). The data were loaded in a decade (10-day period) time unit through the Excel file.

Supply of Groundwater Resources

The supply of groundwater resources data, as input model data, was loaded in a decade time unit through the Excel file. In this case, the groundwater supply calculated by data of agricultural wells (reported by Ilam Regional Water Company, 2015) including operating hours and well discharges.

Water Economy Sub-Model

The sub-system of the water economy includes planting costs, water supply costs (based on surface and underground resources), costs of secondary irrigation and pumping systems, and product prices.

The yield estimation in different water stress scenarios was used with the assumption of uniformity of stress throughout the season from Doorenbos and Kassam (1979) Equation (Equation 10).

$$\frac{Y_a}{Y_P} = 1 - K_Y \left(1 - \frac{\sum_{t=Plantingdate}^{t=harvestdate} ET_{Ct}}{\sum_{t=Plantingdate}^{t=harvestdate} ET_{Pt}}\right) \quad (10)$$

Where, K_y, ET_{Ct}, ET_{Pt}, Y_a, and Y_p are, respectively, the yield response factor of the crop, actual Evapotranspiration, maximum Evapotranspiration, actual harvested Yield, and maximum harvested Yield.

The effect of salinity stress on yield was determined by Maas and Hoffman (1977) Equation.

$$\frac{Y_a}{Y_P} = 1 - b(EC_e - EC^*) \quad (11)$$

Where, ECe, EC*, and b are the mean Electrical Conductivity of a saturated paste taken from the root zone, the salinity threshold expressed in dS m^{-1}, and the slope expressed in percent per dS m^{-1}, respectively.

The salinity of the saturation extract was calculated using the principle of mass conservation in the soil (Equetion12).

Where, ECe is based on dS $m^{-1}$and salinity is based on mg L^{-1}.

In arid and semi-arid regions, most plants are simultaneously affected by salinity and water deficit. The equation proposed in Irrigation and Drainage Journal No. 29 to determine the effect of salinity stress is as (Equetion13).

Environmental Sub-Model

The environmental sub-model includes underground water volume, groundwater salinity (EC), soil salinity (ECe), and Groundwater level (GW level).

The equation of the main variables in these sub-models were calculated from the principle of mass conservation and continuity equation (Soltani *et al.*, 2018).

Statistical Parameters for Model Validation

The model testing was performed in two different approaches: indirect structure tests and testing based on the observational data available. Indirect structure tests involve specialized simulation runs and can provide indirect information about possible flaws in model structures (Saysel and Barlas, 2006). In this study, the structural test of the model was conducted indirectly for each and every single sub-model and for the whole model separately through an indirect structure test (structural behavior test), which is the so-called artificial reality. In order to evaluate the performance of the model, three statistical parameters were used in this study including the Root Mean Square Error (RMSE), the Maximum Error (ME), and the coefficient of determination (R^2).

Evaluated Scenarios

After calibration and validation, the SD model was used to predict how various scenarios of water supply would affect the water resource systems. Different policies could be applied using the tested model after

$$0.64 \times \mathrm{ECe} = \int_{t_0}^{t_n} (\text{Salt added to Soil[crop pattern] - Salt leached from Soil[croppattern]})\,dt + \text{i}\mathit{nitial\ Soil\ Salinity} \quad (12)$$

$$\frac{Y_a}{Y_P} = (1 - b(EC_e - EC^*)) \times \left(1 - K_Y\left(1 - \frac{\sum_{t=\text{Planting date}}^{t=\text{harvest date}} ET_{Ct}}{\sum_{t=\text{Planting date}}^{t=\text{harvest date}} ET_{Pt}}\right)\right) \quad (13)$$

creating the model and ensuring its performance. Policy design is the design of a structure or a new strategy or a change in the rules of decision-making. The water requirement of Dashte Abbas Irrigation Network is about 250 MCM (IRWCBS, 2013, 2014). In the current situation, 50 MCM is supplied through groundwater and the rest through Karkheh water transfer project. Figure 4 shows the cumulative changes in the groundwater level of the plain. The results show that the trend of groundwater level changes had been changed since 2007 and after operation of the irrigation network. After operation of irrigation network, a huge volume of surface water entered the plain. Thus, the demand for groundwater decreased due to higher supply and lower value of the surface water. This condition caused severe drainage problems in the plain. In this research, different water supply scenarios were tested for groundwater level management. The water supply scenarios are as follows:

Scenario 1: Supply 160 MCM of surface water from the Karkheh Dam and withdraw 90 MCM of groundwater (RUN 1),

Scenario 2: Supply 170 MCM of surface water from the Karkheh Dam and withdraw 80 MCM of groundwater (RUN 2),

Scenario 3: Supply 180 MCM of surface water from the Karkheh Dam and withdraw 70 MCM of groundwater (RUN 3),

Scenario 4: Supply 200 MCM of surface water from the Karkheh Dam and withdraw 50 MCM of groundwater (RUN 4).

Scenario No 4 is the current condition and other scenarios are possible policies for water resources management in the plain.

RESULTS AND DISCUSSION

Model Sensitivity Analysis

The sensitivity analysis of dynamic models is different from linear models. In the dynamic model, the user can graphically examine the effects of changing an input parameter on model results. Figures 5 to 7 present the output sensitivity of the key parameters of the model including groundwater level, aquifer static volume, groundwater salinity, and salinity of the soil saturation extract, respectively, compared to input parameters of application efficiency, the coefficient of agricultural water return to the aquifer, and coefficient of variation of reservoir volume per 1 m loss of groundwater level. Change efficiency makes a significant change in all the key variables. The results showed that the sensitivity of the key variables to the Application Efficiency (AE) was higher among all the input

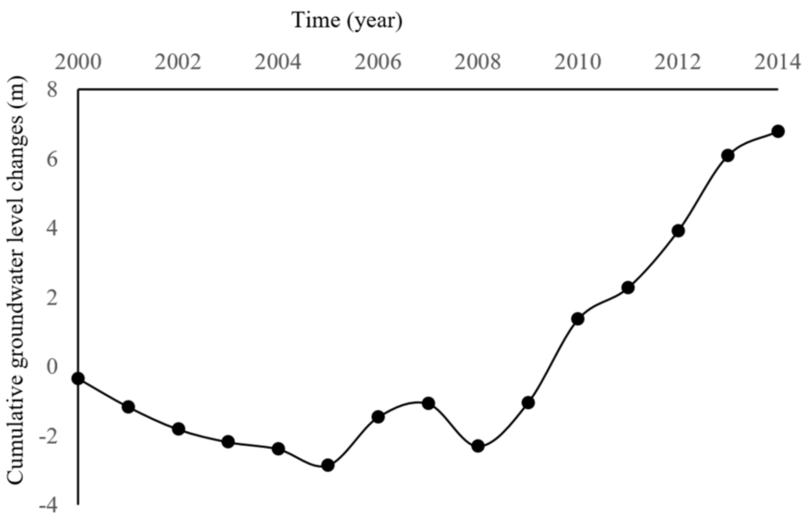

Figure 4. Cumulative groundwater level changes (m).

parameters (Figure 5). The Irrigation Return-Flow Coefficient (IRFC) is another parameter that influences the outputs of the model (Figure 6). The difference between the AE and IRFC is that the AE coefficient includes deep percolation losses, evaporation, and runoff, and much of which does not return to the aquifer, but the IRFC coefficient completely returns to the aquifer. The results show that the developed model is highly sensitive to IRFC coefficient and its increase leads to an increase in the static volume of the aquifer as well as the quality of groundwater due to dilution and the reduction of soil salinity due to leaching. Since most of the model calculations are based on the principle of mass conservation, the aquifer volume change parameter is effective only on the groundwater level to 1 m groundwater loss. The reason is that the static volume of the aquifer is calculated using the principle of mass conservation,

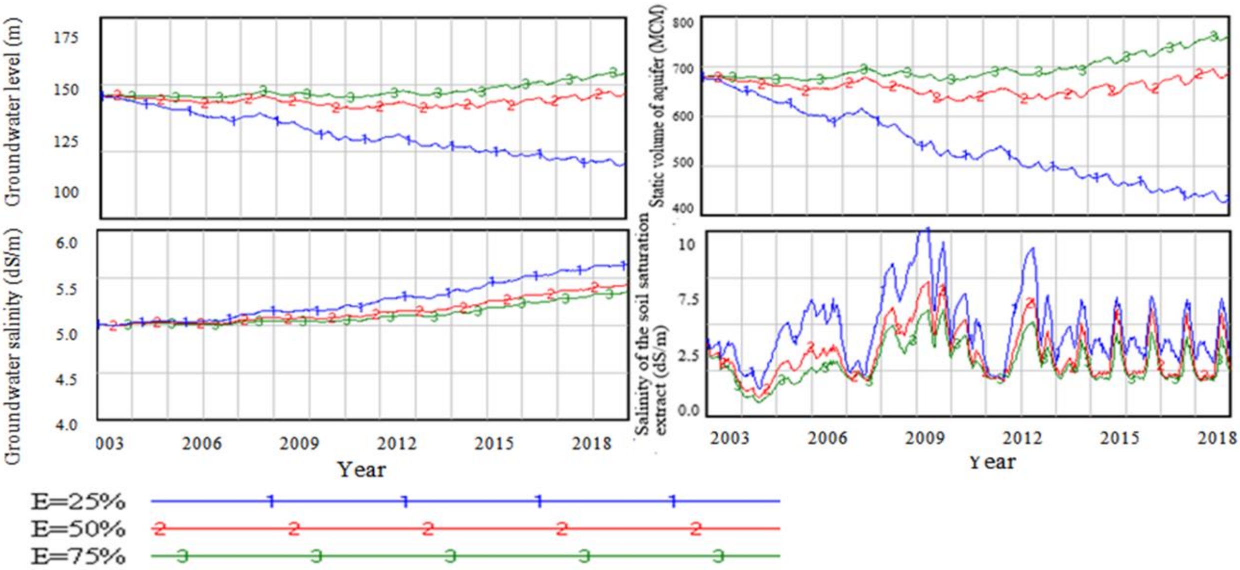

Figure 5. The sensitivity of some of the key variables of the model to the application efficiency.

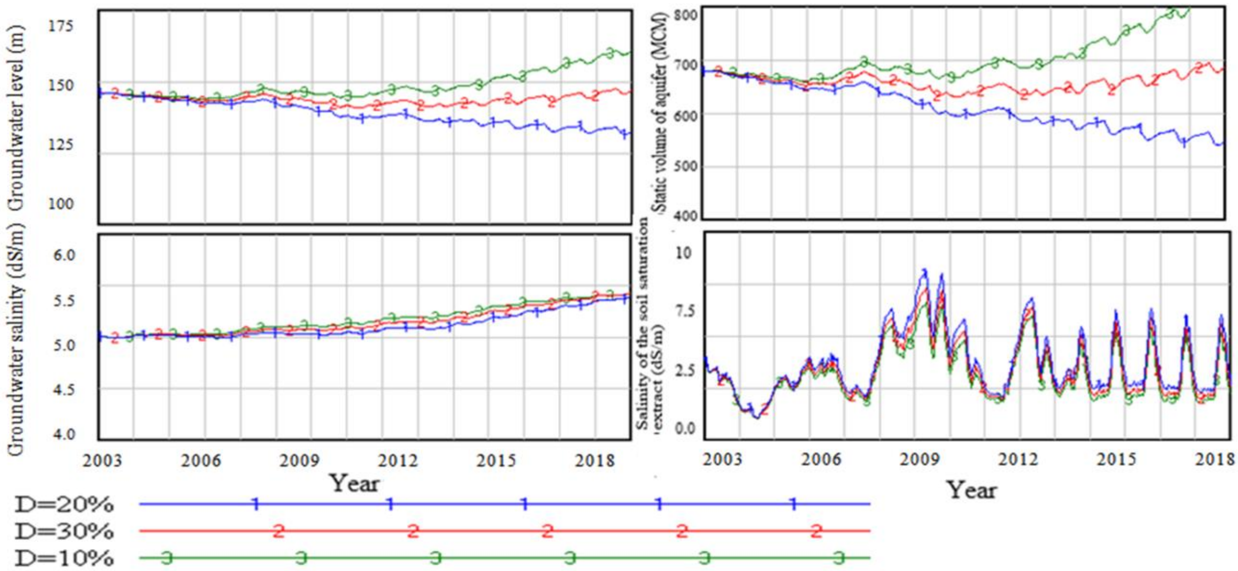

Figure 6. The sensitivity of some of the key variables of the model to the irrigation return-flow coefficient.

then, other parameters, including the groundwater level was calculated using the aquifer volume changes (Figure 7).

The Extreme-Condition Test

For model validation under extreme conditions, the model was rune for the extreme conditions of absence of irrigation network. Figure 8 illustrates the behavior of key variables, including groundwater salinity, groundwater level, aquifer volume, and evaporation from the aquifer surface in the absence of Dashte Abbas Network (extreme-condition). The results show that in the absence of network development, the aquifer volume and groundwater level are reduced due to excessive withdrawal. The evaporation from the surface of the aquifer also decreases due to the groundwater level loss. Groundwater quality also decreases over time. The extreme-condition test results indicate that the existing conditions

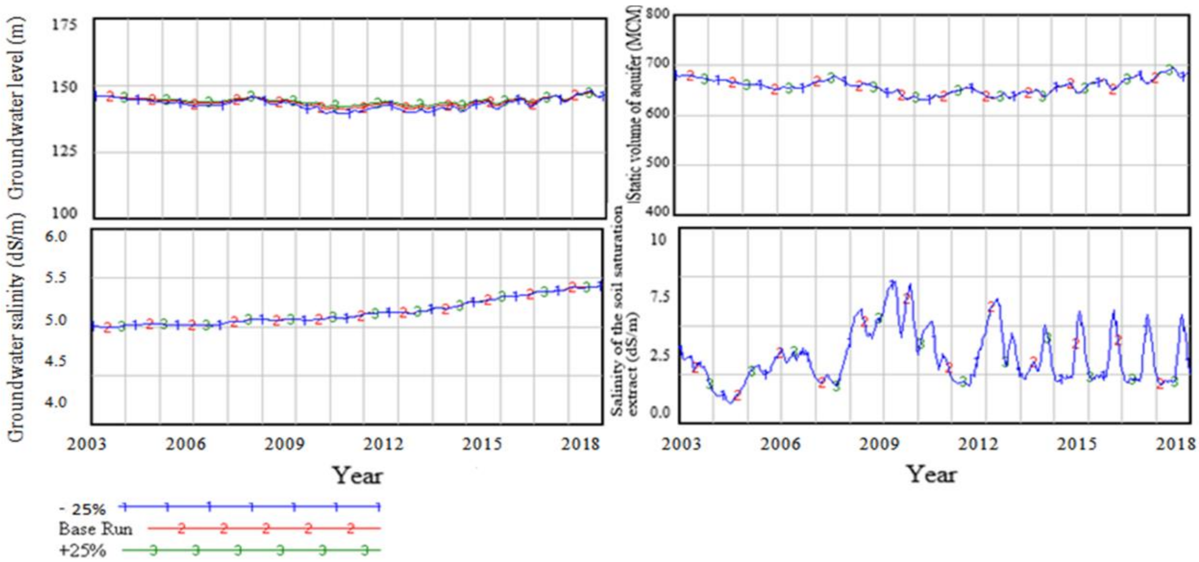

Figure 7. The sensitivity of some of the key variables of the model to the change rate in aquifer volume to 1m groundwater loss.

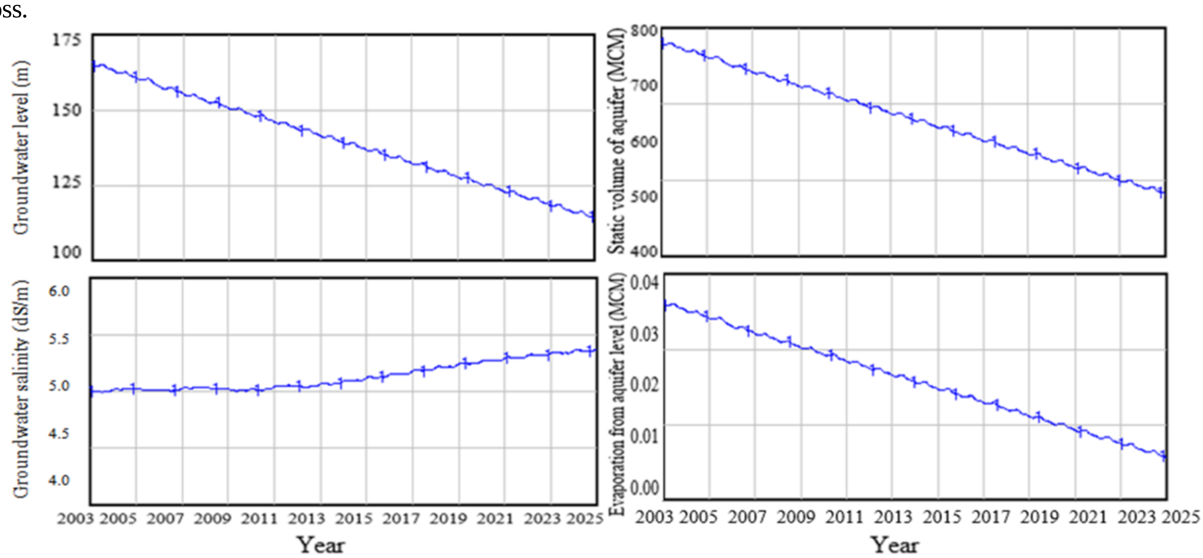

Figure 8. The behavior of key variables in the extreme-condition of the absence of network development.

(groundwater loss and groundwater quality reduction) will continue if the network is not developed, indicating the accuracy of the developed model in the extreme-condition.

Model Validation

The structural evaluation model, dimensional accuracy, limit conditions, and model behavior tests were conducted to validate the model.

Figure 9 shows the simulated and relative observational yield of forage corn at different levels of water consumption. In addition, Figure 10 presents the consistency and correlation of simulated yield with the observed values. The results show the accuracy of the model in estimating the relative yield in the range of 40 to 100% of the water requirement. The model has higher capabilities than crop models due to the requirement of low parameters, simple calibration, linkability with basin area, dynamics due to long-term time changes, as well as acceptable estimation in economical irrigation intervals.

Figure 11 depicts the consistency and correlation of the water level simulated by the model with the measured data. The results show the ability of the model to estimate the groundwater level (RMSE= 49 cm, R2= 0.97, and The maximum error= 82 cm). The maximum model error in the estimation of the groundwater level is related to 2007-2008. There was no accurate information on the amount of unauthorized groundwater withdrawal due to the severe drought. Since the groundwater level in the model is calculated based on the mass balance equation, the accuracy of the results depends on the accuracy of the input data. However, the use of long-term average climatic and hydrological parameters data is sufficient to predict long-term groundwater levels.

Evaluation of the Policies Scenarios

Figure 12 shows the effects of different surface and groundwater supply scenarios on the groundwater level, aquifer volume, groundwater salinity, and evaporation from the aquifer surface. Also, Figure 13 indicates the effects of different surface and groundwater supply scenarios on the groundwater depth. The results show that application of the fourth scenario would increase the groundwater level and reduce the depth of the groundwater level such that the groundwater level reaches the ground level by 2025 through this scenario and causes problems in cultivation. In this situation, the only possible way to meet the

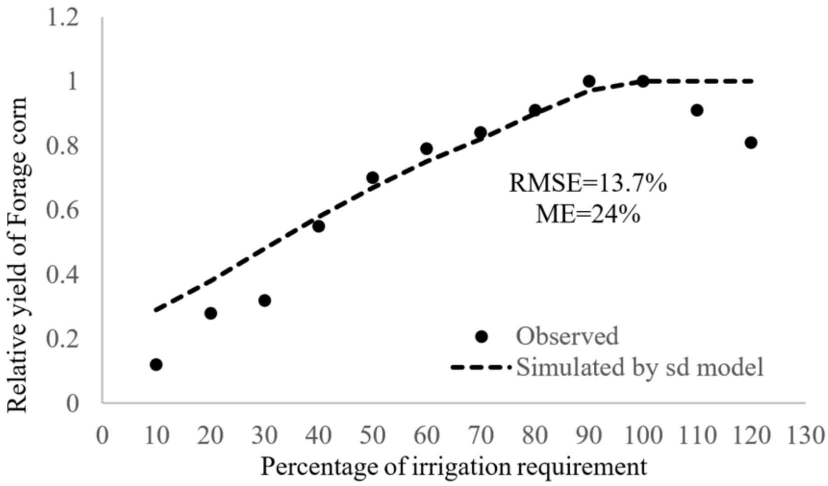

Figure 9. Comparison of the simulated and relative observed yield of forage corn at different levels of water consumption.

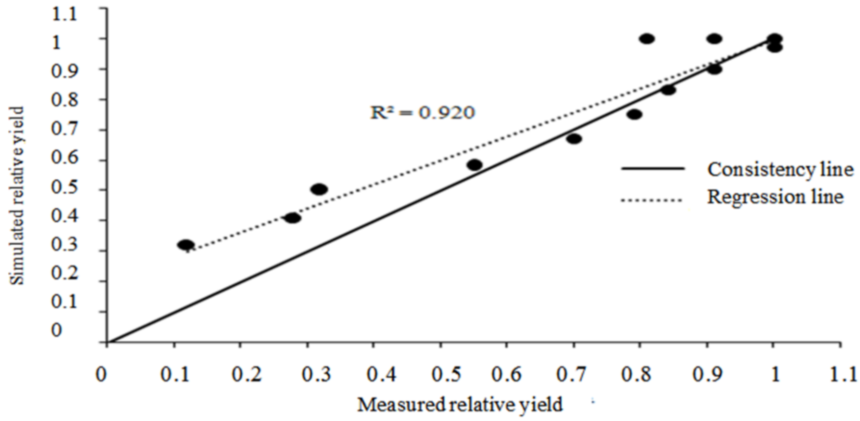

Figure 10. Simulated relative yield versus the observed yield of forage corn.

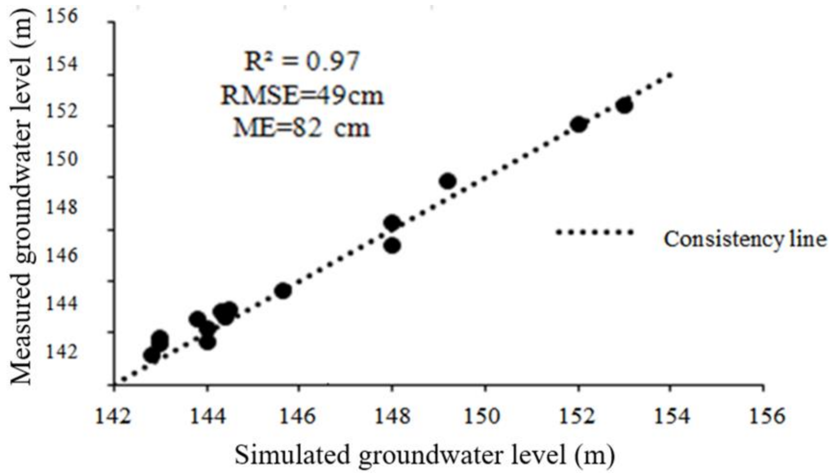

Figure 11. Simulated groundwater level (m) versus measured groundwater level (m).

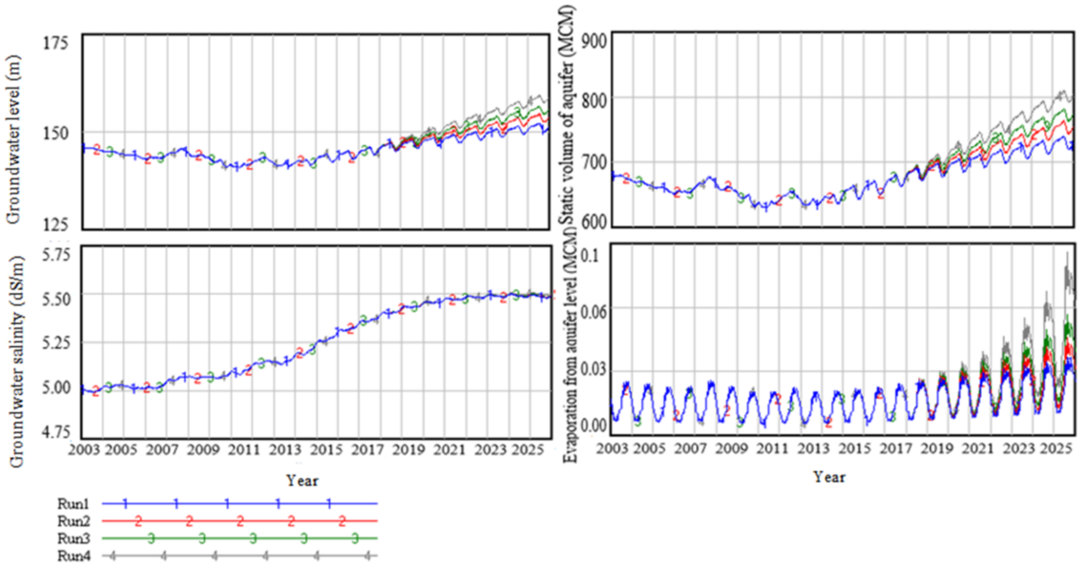

Figure 12. Evaluating the effect of Karkheh Dam water supply scenarios on some of the key variables.

overflow problems is to install a drainage network in the plain, which entails enormous expenses. The results also indicate that the need for drainage is reduced with increasing groundwater consumption so that applying the first option causes a balance in the plain aquifer, and the groundwater level in this option fixes on about 5 to 10 m. Evaporation from groundwater decreases with decreasing groundwater level, which itself indicates the capability of the model and its accuracy in estimating groundwater balance parameters. Therefore, the first scenario seems to be the best choice to reduce the maximum cost.

Figure 14 shows the net income of each option. As can be observed, option 1 has the highest income, and the fourth option has the lowest income. Increasing the groundwater levels causes water-logging and reduction of yield. Therefore, due to reduced water-logging problems and the lack of transfer of saline water to the root zone, option 1 increases the crop yield.

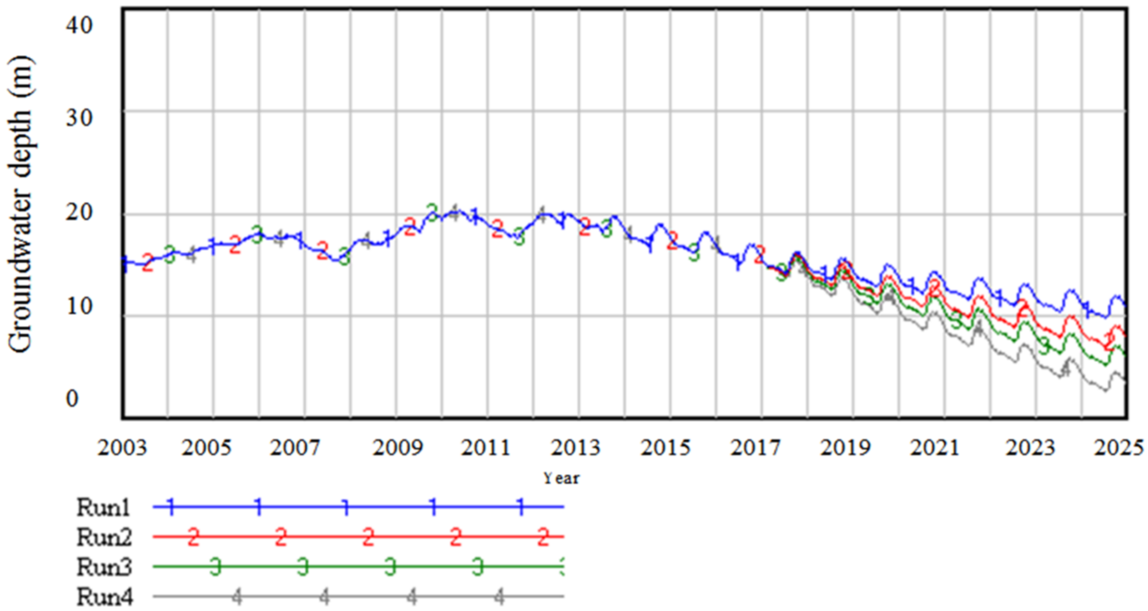

Figure 13. Evaluating the effect of Karkheh Dam water supply scenarios on groundwater depth (m).

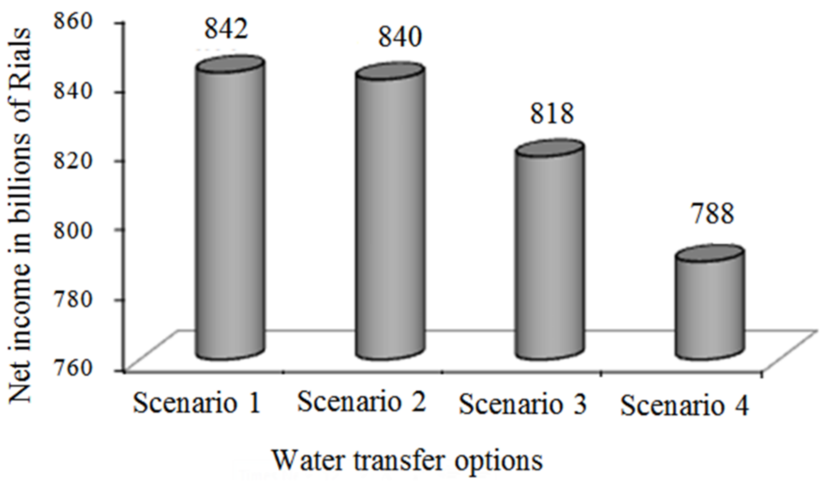

Figure 14. The effect of Karkheh Dam water supply scenarios on net income.

CONCLUSIONS

The comprehensive management of water resources in the basin scope, the interaction of components within the system, and the interactions of different systems should be considered comprehensively. This study was conducted in Dashte Abbas Plain, with an emphasis on solving the problem of water-logging in this plain using the System Dynamics (SD) approach. Vensim software was used for simulation and development of the dynamic model. The SD modeling was carried out in three main stages: (i) Drawing causal loop diagrams, (ii) Modeling the interrelationship among variables, and (iii) Testing the model and developing the final model. The conceptual model was considered based on five sub-models, including water demand, water supply, environmental stresses, environment, and water economics. The four evaluated water transfer scenarios were allocation of 160, 170, 180, 200 Million Cubic Meters (MCM) water transferred from the Karkheh Dam and 90, 80, 70, and 60 MCM annual groundwater withdrawal from the aquifer, respectively. The results showed that all scenarios of water transfer increased groundwater level, salinity in the root zone, and drainage problems, decreased groundwater quality, and agricultural crop yield in the plain. The results of the SD model demonstrate that the need for drainage is reduced with increasing groundwater consumption. The alternative cropping systems with higher water requirements, including forage crops and sugar beet, may be helpful to reduce drainage problems and to prevent the construction of an underground drainage systems. The results also confirmed that with the implementation of the first water allocation scenario (allocation of annual 160 MCM surface water transfer and annual withdrawal of 90 MCM of groundwater) and cultivation of higher water-requirement crops can reduce the increase in groundwater level and drainage problems. In these conditions, the water table remains almost constant at a depth of 10 meters.

ACKNOWLEDGEMENTS

The authors wish to thank the Razi University of Kermanshah for funding this study.

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تعیین بهترین سناریوی عرضه آب سد کرخه به منظور جلوگیری از مشکلات زهکشی دشت عباس با استفاده از رویکرد پویایی سیستم

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چکیده

دشت عباس یکی از دشت‌های مهم استان ایلام واقع در جنوب غرب ایران می‌باشد. یکی از مهمترین محدودیت‌های توسعه کشاورزی در ایران محدودیت منابع آب می‌باشد. پروژه انتقال آب از سد کرخه به دشت عباس با هدف رفع مشکل کمبود آب منطقه در سال ۲۰۰۸ به بهره‌برداری رسید. هدف از این مطالعه بررسی سناریوهای مختلف مدیریت منابع آب بر شرایط اقتصادی و زیست‌محیطی دشت عباس با استفاده از روش پویایی سیستم‌ها بود. مدل مفهومی شامل پنج زیر مدل تقاضای آب، عرضه آب، تنش‌های محیطی، اقتصاد آب و محیطزیست می‌باشد. سناریوهای عرضه آب مورد ارزیابی شامل تخصیص ۱۶۰، ۱۷۰، ۱۸۰ و ۲۰۰ میلیون مترمکعب از سد کرخه و مصرف سالانه ۹۰، ۸۰، ۷۰ و ۶۰

میلیون مترمکعب از آب زیرزمینی دشت می‌باشد. نتایج نشان داد که در همه سناریوهای انتقال آب از سد کرخه باعث افزایش تراز آب زیرزمینی، کاهش کیفیت آب زیرزمینی، کاهش تهویه خاک، افزایش شوری منطقه توسعه ریشه و به تبع آن کاهش عملکرد محصولات کشاورزی می‌شود. همچنین نتایج اجرای مدل نشان داد که با افزایش برداشت آب زیرزمینی نیاز به زهکشی کاهش پیدا می‌کند. استفاده از منابع آب زیرزمینی و استفاده از الگوی کشت پر مصرف با تأکید بر افزایش سطح علوفه و چغندر می‌تواند باعث کاهش مشکلات زهکشی و کاهش هزینه‌های اجرای شبکه زهکشی شود. نتایج ارزیابی سناریوهای مختلف عرضه نشان داد که اجرای سناریوی اول (تخصیص ۱۶۰ میلیون متر مکعب از سد کرخه و برداشت ۹۰ میلیون متر مکعب از آبخوان دشت) به همراه کاشت الگوی کشت پرمصرف موثرترین سناریو برای کاهش مشکلات زهکشی دشت می‌باشد. در این شرایط سطح آب زیرزمینی در عمق ۱۰ متری از سطح زمین تثبیت می‌شود.