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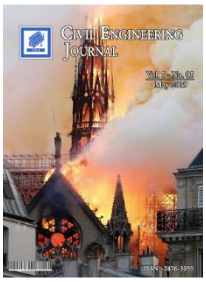

Economic and Environmental Impacts of Cropping Pattern Elements Using Systems Dynamics

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Abstract

Tragedies arising from poor water resources management and planning are significantly more relevant than climate change and frequent natural droughts, especially in arid and semi-arid areas. Nearly 92% of total water is allocated to the agricultural sector in Iran. In this situation, cultivation patterns play an important role in agricultural water management. Evaluating the effect of each crop would help the stakeholders make a rational decision in choosing appropriate cropping patterns to avoid groundwater depletion as well as maintain their livelihoods. The Qazvin plain in Iran, whose aquifer has had a drawdown of nearly 20m during the last 15 years, was used in this case study. It has been modeled using system dynamics, which includes two subsystems: hydrology, for calculating groundwater level, and economy, for defining farmer's income in the years from 1997 to 2011. The system dynamics, which included 17 crops, was developed after calibration by simple genetic algorithm and verification under extreme condition tests. To identify the economic and environmental effect of each of the crops, the system dynamics was run 18 times, removing crops one by one. It has been found that wheat plays an important role in causing a negative water balance but does not affect the farmers' incomes as significantly as grapes. Two indicators, which included sustainable water resources and water exploitation, were employed to assess the scenarios as well. According to the results, no scenarios are fully sustainable for maintaining a steady aquifer, but scenario 1, which removed wheat from the cropping pattern, is the most sustainable and puts the least pressure on the aquifer.

Keywords: Groundwater Level; System Dynamics; Farmers' Income; Sustainability; Wheat.

1. Introduction

Recently, increasing population, climate change, industrialization, urbanism, etc. have been affecting water resources-especially aquifers. Very often in arid and semi-arid countries, farmers use natural resources unwisely in order to survive. This kind of behavior causes a crisis in job security, drinking demand and food security. The long-term decreasing groundwater level has resulted from many reasons such as weak policy, drought, inappropriate management and planning of water resources. Since both groundwater level and farmers' income are affected by cropping pattern, defining an appropriate cropping pattern is an imperative issue that should be noted [1–4]. Consequently, both decreasing groundwater depletion and increasing the farmers' income are essential considerations [4–7]. Cropping pattern could be

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impacted by many factors such as policy change, importing and exporting rules of agricultural products, climate, product demands, water supply, job opportunities and so on.

During recent years, a large number of studies, many of which are based on cropping pattern optimization, have been done [2, 5, 6, 8–12]. Fazlali et al. [13] used a coupled simulation-optimization model to determine the optimal cropping pattern in the Arayez plain in the Karkheh river basin in Iran. By integration of Network Flow Programming (NFP) as simulation model, and the Shuffle Frog Leaping Algorithm (SFLA) as optimization model, the total net benefit gained from crop production was maximized. The results of the coupled SFLA-NFP model show that the net benefit increases 12% compared to the present situation in the plain. Jebelli et al. [14] developed a model to maximize farmers' gross income by optimizing the cropping pattern while satisfying all of the imposed constraints in the Tigray region in Ethiopia. Its constraints included water demand, crop disease, and pest resistance, market price, level of fertilizer input, intensity of labor requirement, capital requirements, and post-harvest processing requirements. The results showed that the percentages of only two crops; tomato-from 5% to 8%, and barley-from 3% to 44%, were increased in the optimal cropping pattern. Osama et al. [15] developed alinear programming to optimize land allocation in order to maximize the net annual income of three old areas of Egypt. In the model, different constraints such as water availability, land availability in different seasons of the year, self-sufficiency ratios, and actual areas of crops under existing patterns of cropping were applied to optimize the cropland of 28 crops in the years from 2008 to 2012. The results showed that the benefits are increased by an average of 6.66% ±0.84 over the modeling period. Varade et al. [8] defined a multi-objective optimization problem to determine optimal cropping pattern for maximizing the net annual returns and conserve groundwater resources simultaneously. The cropping patterns of 33 crops were optimized using two PSO and Jaya algorithms and the results led to higher income and less water allocation compared to the existing cropping pattern. Youse et al. [16] developed a model that included three objective functions that would maximize the benefits, reduce nitrogen leaching, and improve the rate of aquifer recharge, both together and separate. In the developed model, Particle Swarm Optimization (PSO) integrated with an additive weighting method and a Multi-Objective Particle Swarm Optimization (MOPSO) algorithm were used to find the optimal cropping. The results showed that it is possible to increase water efficiency; while increasing farmers' benefits, and decreasing nitrogen leaching. Rath et al. [17] identified a suitable cropping pattern through optimization techniques such as LINDO and Genetic Algorithm. The developed cropping pattern gave the net benefit of about 46% more than the present habit.

The literature review shows previous studies did not mention the impacts of each single crop of the cropping pattern on the farmers' income and groundwater level, nor did they focus on over time. This research is concerned with evaluating the effect of each crop on groundwater drawdown and the farmers' income simultaneously over the same period.

2. Materials and Methods

2.1. Case Study

The Qazvin aquifer, in Iran, is one that has a negative balance. As figure 1 shows, the average yearly decrease in groundwater level is 1.3 m. The aquifer is the most important **resource** in the Qazvin plain for all demands such as drinking, industry, and agriculture. Farmers are the main groundwater users, by 1200 MCM. Additionally, the income of most people in the Qazvin plain is extremely dependent on agriculture. Therefore, the aquifer plays an important role in the economy of this area.

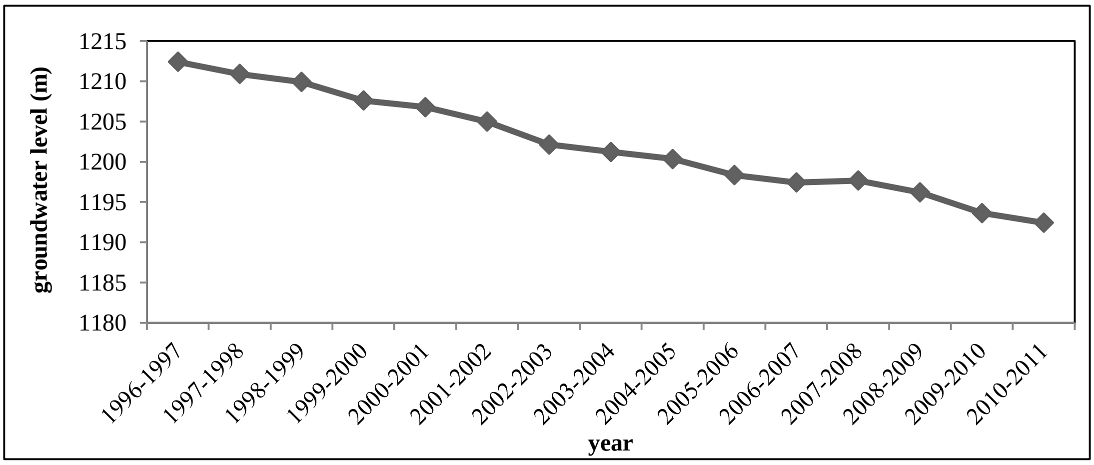


Figure 1. History of groundwater levels over 15 years

Figure 2 indicates the location of the Qazvin plain, its climate classification as well as its water resources. The Qazvin plain's needs are provided by transfer water from Taleghan dam, some rivers such as Khar Rood, Abhar Rood, and Haji

Arab Rood and its aquifer. To model the case study, the system dynamics was used as an adequate tool. The system dynamics of the Qazvin plain has two subsystems including hydrology and economy, which will be described in the next section.

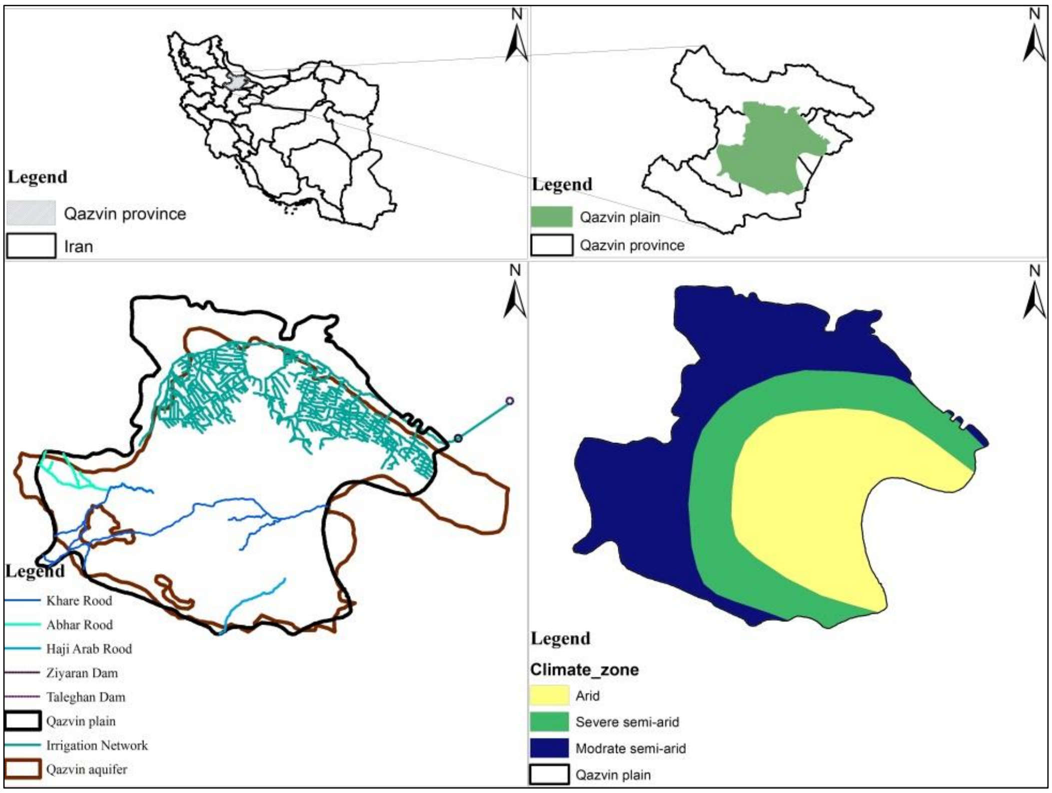


Figure 2. Location map of case study

Following flowchart shows the steps that have been taken in doing the study (Figure 3). Each stage of the research is explained in detail as follows.

-Develop a SD including two subsystems: hydrology, and economy

-Calibrate the SD using a Simple Genetic Algorithm (**SGA**) to minimize the residuals

- Run the SD for the actual condition with 17 crops (Scenario 0)

- Design Scenarios

For crop i=1:17

-Remove crop i (scenario i^{th})

-Run the new SD with 16 crops

-Calculate the Farmers' Income Deficiency (FID %) and the Avoiding Drawdown (ADW %) by removing crop i over 15 years

-Calculate average annual SUI and WEI+

End for

Figure 3. Flow chart of research methodology

2.2. System Dynamics

System dynamics (SD) is an approach to understanding the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, and time delays [18–20]. Additionally, it makes it possible for us to model action and reaction of physical and non-physical factors on each other as if we can evaluate the reaction of the extraction of the aquifer on employment and so on. The Qazvin plain is modeled using two subsystems: hydrology, and economy.

2.2.1. Hydrology Subsystem

The subsystem has two main stock variables including surface water and groundwater.

2.2.1.1. Groundwater

The Qazvin plain has the main aquifer located in the middle of the plain. The aquifer has an important role in growing agriculture and it is the most important water resource in the plain as well. Therefore, conserving the aquifer is essential to guaranteeing appropriate living conditions in the area for the future.

The groundwater volume is the stock variable of the subsystem that is calculated by subtracting inflow from outflow (Figure 4). The groundwater volume in each year and cumulative groundwater volume was computed using Equations 1 and 2 respectively.

$$\Delta S_{G,t} = Q_{GI,t} - Q_{Go,t} \tag{1}$$

$$S_{G,t} = \Delta S_{G,t} + S_{G,t-1} \tag{2}$$

Where, $\Delta S_{G,t}$ is the change in groundwater storage in year t (MCM), $Q_{GI,t}$ is the amount of inflow into the aquifer in year t (MCM), $Q_{Go,t}$ is the amount of outflow from the aquifer in year t (MCM), $S_{G,t}$ is the cumulative groundwater volume in the aquifer until year t (MCM), and $S_{G,t-1}$ is the cumulative groundwater volume until year t-1 (MCM).

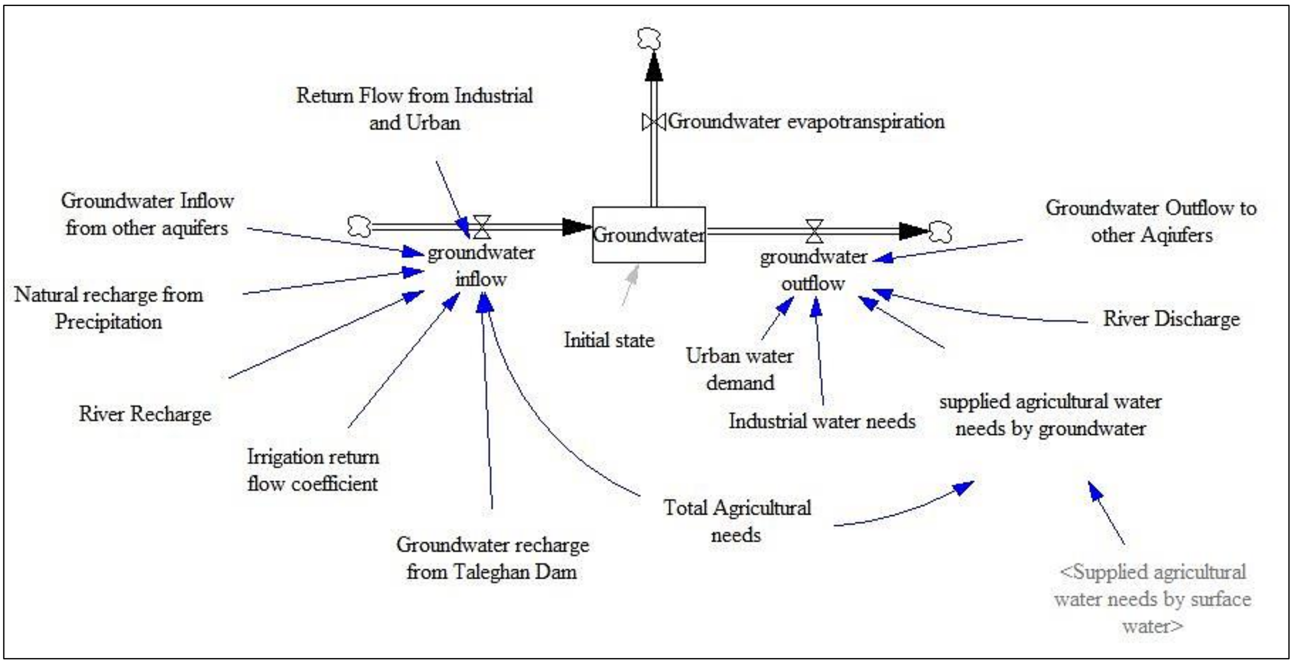


Figure 4. Flow diagram of groundwater stock

Then, the amount of inflow and outflow of the aquifer are calculated by Equations 3 and 4.

$$Q_{GI,t} = D_{agri,t} \times RC_{agri} + S_R + Re_{TD,t} + Re_{r,t}^{G} + IF_{an}^{G} + (D_I + D_{Dr}) \times RC_{I,DR} \tag{3}$$

$$Q_{GO,t} = D_I + D_{Dr} + D_{agri,t}^{G} + E_G + OF_G + Dr_R \tag{4}$$

Where, RC_{agri} is the return flow coefficient to estimate the return water from irrigation, S_R is the amount of seepage from the river (MCM), $Re_{TD,t}$ is the amount of artificial recharge from Taleghan dam in year t (MCM), $Re_{r,t}^{G}$ is the amount of precipitation recharge in year t (MCM), IF_{an}^{G} annual average recharge by other aquifers (MCM), D_{Dr} is the average annual urban demand (MCM), D_I is the average annual industrial demand (MCM), $RC_{I,DR}$ is the return coefficient from extracted water usage for urban and industry needs, $D_{agri,t}^{G}$ is the amount of water that was allocated to industry and urban demand (MCM), E_G is the amount of evaporation from the aquifer (MCM), OF_G is the annual average recharge from other aquifers nearby (MCM), and Dr_R is the amount of groundwater discharge to river (MCM).

Then, the amount of the equivalent groundwater level in year t is computed using Eq. 5.

$$GW\_l_t = \frac{S_{G,t}}{A_{aq} \times S} \tag{5}$$

Where, GW_l_t is the groundwater level in year t, S is the coefficient storage of the aquifer, and A_{aq} is the area of the aquifer.

2.2.1.2. Surface Water

The most important surface water resource in the plain comes from Taleghan dam. Nearly 10% of it is allocated to recharge the aquifer using recharge wells and the remains feed the irrigation network which is located in the northern part of the plain (Figure 2).

Because there is not a reservoir in the plain, changes in storage should be zero (Eq.6). Some water is lost through evaporation and flow into other watersheds, while the rest is consumed by the irrigation network (Figure 5).

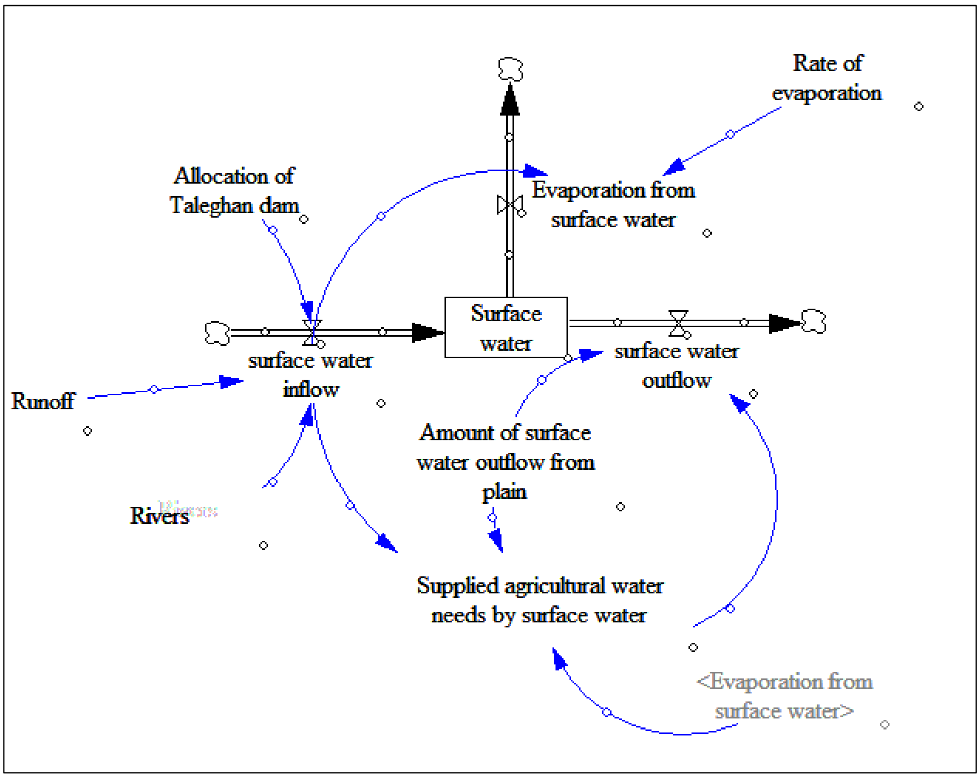


Figure 5. Flow diagram of surface water stock

$$Q_{SI,t} = Q_{So,t} \tag{6}$$

Where, $Q_{SI,t}$ *and* $Q_{So,t}$ are the amount of inflow and outflow surface water respectively which are calculated using Equations 7 and 8.

$$Q_{SI,t} = Al_{Ta,t} \times 0.9 + RF_t + RI \tag{7}$$

$$Q_{So,t} \ = OF_S + E_S + D^S_{agri,t} \tag{8}$$

Where, $Al_{Ta,t}$ is the allocation from Taleghan dam into the irrigation network in year t (MCM), RF_t is the amount of the runoff in year t (MCM), RI is the inflow from the main rivers into the plain (MCM), OF_S is the surface water outflow from the plain (MCM), E_S is the amount of the evaporation (MCM), and $D^S_{agri,t}$ is the amount of the surface water used for gross irrigation demand (MCM).

2.2.2. Economic Subsystem

Seventeen crops that occupy most cropland in the Qazvin plain were introduced to SD. In this subsystem, yields and water consumption of crops were assigned as a function of cropland, unit yields and unit water demand (Figure 6). Water consumption of each crop was determined using Equation 9 and historical data that was collected by the agricultural office.

$$WROC^t_Z = \ AWROC_Z \ \times \ CL^t_Z \tag{9}$$

Where, WROC^t_Z is the total net water consumption of crop Z in year t (MCM), AWROC_Z is the net average water consumption of crop z in the Qazvin plain, and CL^t_Z is the cropland of crop Z in year t. Then, the total gross water requirement of all crops was computed by Equation 10.

$$D_{agri,t} = \sum WROC^t_Z \times \frac{1}{EP} \tag{10}$$

Where, $D_{agri,t}$ and EP are the total gross irrigation water needing in year t and the irrigation system efficiency respectively.

The total farmers' net income during the studied period was computed using Equations 11 and 12.

$$TNI_{net}^{t} = NI_{net}^{t} + TNI_{net}^{t-1} \tag{11}$$

$$NI_{net}^{t} = GI_{total}^{t} - \sum Y_z^t \times C_z \tag{12}$$

Where, TNI_{net}^{t} is the farmers' total net income until year t ($), NI_{net}^{t} is the farmer's net income in year t ($) calculated using Eq.12, TNI_{net}^{t-1} is the farmers' total net income until year t ($), GI_{total}^{t} is the total gross farmers' income in year t ($), Y_z^t is the total production of crop Z in year t (ton), and C_z is the cost of crop production z in dollar per ton.

To calculate the amount of products in each year (Equation 13), historical data was used, which shows the amount of yield per hectare of each crop in the Qazvin plain.

$$Y_z^t = Unit\_Y_z^t \times CL_z^t \tag{13}$$

Where, $Unit\_Y_z^t$ is the crop yield of crop z in year t (ton).

The gross income of the farmers was calculated in year t using Equation 14.

$$GI_{total}^{t} = \sum Y_z^t \times Pr_z^t \tag{14}$$

Where, Pr_z^t is the price of crop Z in year t ($).

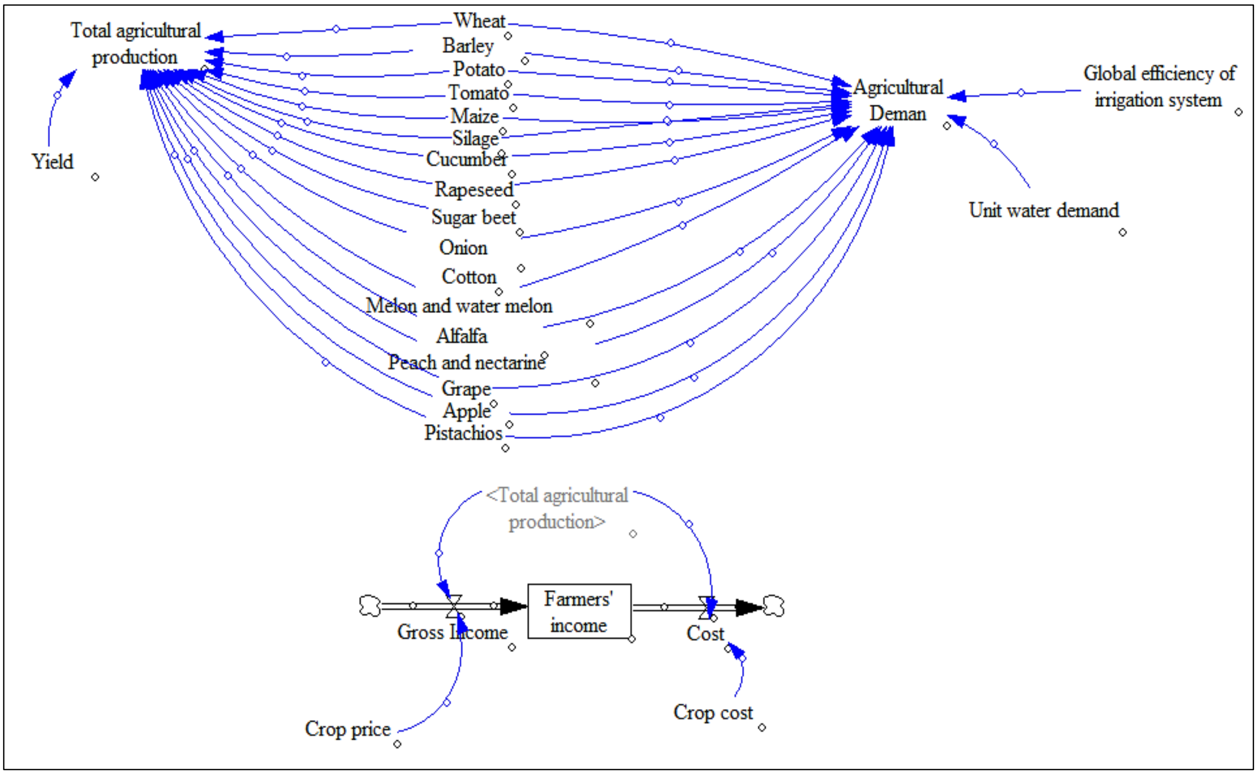


Figure 6. Flow diagram of the economic subsystem

2.3. Calibration of Model

Because of variety of crops that are grown in the case study that occupied less cropland but didn't consider in the model the SD model was calibrated to meet the historical data. To do this, a Simple Genetic Algorithm (SGA) as an optimization model was employed. The objective function of SGA (Eq. 15) was defined in such a way that leads to reducing the difference between simulated and observed groundwater levels from 1997 to 2011.

$$minmize \ \frac{\sum_{i=1}^{15}(GL_{Ob}^{t} - GL_{SI}^{t})^2}{15} \tag{15}$$

Where, GL_{Ob}^{t} and GL_{SI}^{t} are the observed and simulated groundwater level in year t respectively.

2.4. Scenarios

To evaluate the effect of each crop on the water resources and farmers' income, by eliminating crops one by one, different scenarios were defined (Table 1). In each scenario, while one crop was eliminated and others remained unchanged, groundwater levels and the farmers' total net income over fifteen years were calculated.

Farmers' income, based on the historical data, was considered as farmers' potential income, therefore the deficit of farmers' income could be calculated in each scenario. Using groundwater level as the environmental factor in each scenario, scenario 0 was used as a benchmark. Then the amount of avoiding drawdown and the percentage of the income deficiency were calculated using Equations 16 and 17.

$$ADW = \frac{DW_{max} - DW_{SCi}}{DW_{max}} \times 100 \quad (16)$$

$$FID = \frac{FI_{max} - FI_{SCi}}{FI_{max}} \times 100 \quad (17)$$

Where, ADW is the percentage of avoiding drawdown (%), DW_{max} is the maximum drawdown, which is resulted during fifteen years (m), DW_{SCi} is the drawdown that would arise from scenario i (m), FID is the percantage of the Farmers' Income Deficiency (%), FI_{max} is the maximum farmer's net income, which farmer earned during 15 years (billion dollars), and FI_{SCi} is the farmers' net income that would be gained in scenario i (billion dollars).

Table 1. Detail of scenarios

No.	Name of scenario	Information
1	Scenario 0	historical cropping pattern
2	Scenario 1	Remove wheat
3	Scenario 2	Remove barley
4	Scenario 3	Remove potato
5	Scenario 4	Remove tomato
6	Scenario 5	Remove maize
7	Scenario 6	Remove silage
8	Scenario 7	Remove cucumber
9	Scenario 8	Remove rapeseed
10	Scenario 9	Remove sugar beet
11	Scenario 10	Remove onion
12	Scenario 11	Remove cotton
13	Scenario 12	Remove melon and watermelon
14	Scenario 13	Remove alfalfa
15	Scenario 14	Remove peach and nectarine
16	Scenario 15	Remove grapes
17	Scenario 16	Remove apple
18	Scenario 17	Remove pistachios

2.5. Evaluating Indicator

To evaluate the impact of each scenario on the aquifer and farmers' income two indicators were developed, Sustainable Index (SUI) and Water Exploitation Index (WEI+).

2.5.1. Sustainable Index (SUI)

To quantify the sustainability of water resources systems in each scenario as well as evaluate and compare them with each other this index was employed which is calculated using Equation 18 [22]. A negative value of SUI indicates the extra water usage and a positive value indicates the proper water abstraction strategies.

$$SUI = \frac{Q_{GI} - D^{G}_{agri} - D_I - D_{Dr}}{Q_{GI}} \quad (18)$$

Where, SUI is the sustainable index, Q_{GI} is the average annual recharge (MCM), D^{G}_{agri}, D_{Dr} and D_I are the average annual agriculture, urban and industrial demand respectively (MCM).

2.5.2. Water Exploitation Index (WEI+)

The index represents the pressure of water abstraction on the available freshwater resources [22]. The index could be defined as the ratio of average annual demands into average recharge. To solve the uncertainty in the assessment of demands and water resources values, a modified water exploitation index (Equation 19) called WEI+ has been developed [23]. The near zero value shows less pressure on the aquifer.

$$WEI+ = \frac{D^{G}_{agri} + D_I + D_{Dr} - R_{UW}}{Q_{GI} - R_{UW}} \times 100 \quad (19)$$

Where, $WEI+$ is the modified water exploitation index (%), and R_{UW} is the total return water (MCM).

3. Results and Discussion

3.1. Model Calibration

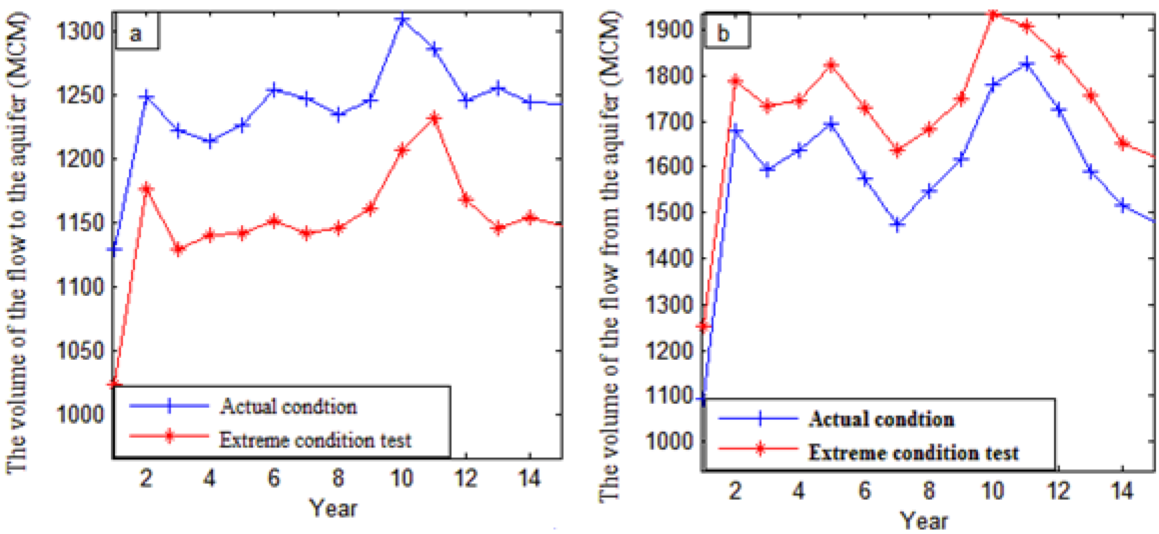
To check the accuracy of the SD model that was developed in Matlab, all simulated stock variables were compared with the values that were computed using Vensim over the simulated period. Then, our model was calibrated by a simple genetic algorithm to reduce error between the simulated and measured data. Table 2 shows the statistical indicators before and after calibrating. As the data shows, the objective function has a mean square error of 3.07 after calibration.

Table 2. The statistical indicators before and after calibrating

Statistical index	After calibration	Before calibration
MSE	3.07	1992.717
R^2	0.97	0.34

3.2. Model Verification

Following, some extreme conditions were applied to verify the model. To explain, the impact of zero rainfall on the rest of the variables affected from rainfall over the fifteen years, was evaluated. As Figure 7 shows, if rainfall reaches zero, the amount of aquifer and surface water inflow decreases (Figures 7.a and 7.c). In this condition, in order to meet all of the demands, the amount of depletion would rise; therefore, the amount of aquifer outflow would increase (Figure 7.b). Consequently, the potentiometric surface will be less than the actual value in each year (Figure 7.d).



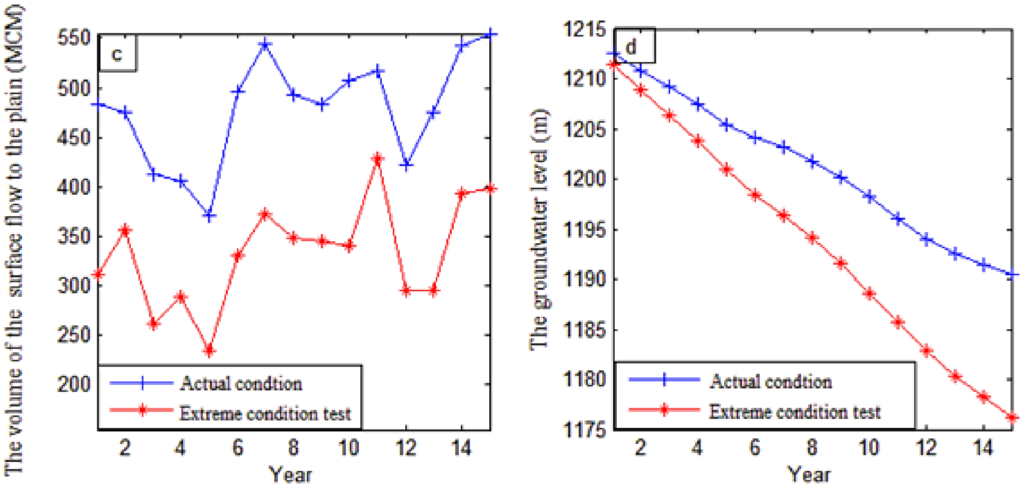


Figure 7. Verification test of SD by assuming rainfall to be zero. (a) The changes of the volume of flow into the aquifer; (b) The changes of the volume of flow from the aquifer; (c) The changes of the volume of the surface flow to the plain; (d) The changes of groundwater level

In the next extreme condition test, the water allocation from Taleghan dam was assumed to be zero and then its impacts were evaluated (Figure 8). If water allocation from Taleghan dam is assumed as zero, the amount of the aquifer inflow is decreased because nearly 10% of this allocated water is used to recharge the aquifer as well as surface inflow which is supplied by Taleghan dam (Figures 8.a and 8.c). In addition, since some of the irrigation demand is provided by Taleghan dam, this assumption would require more extracting from the aquifer and put the groundwater level lower than the actual amount (Figures 8.b and 8.d).

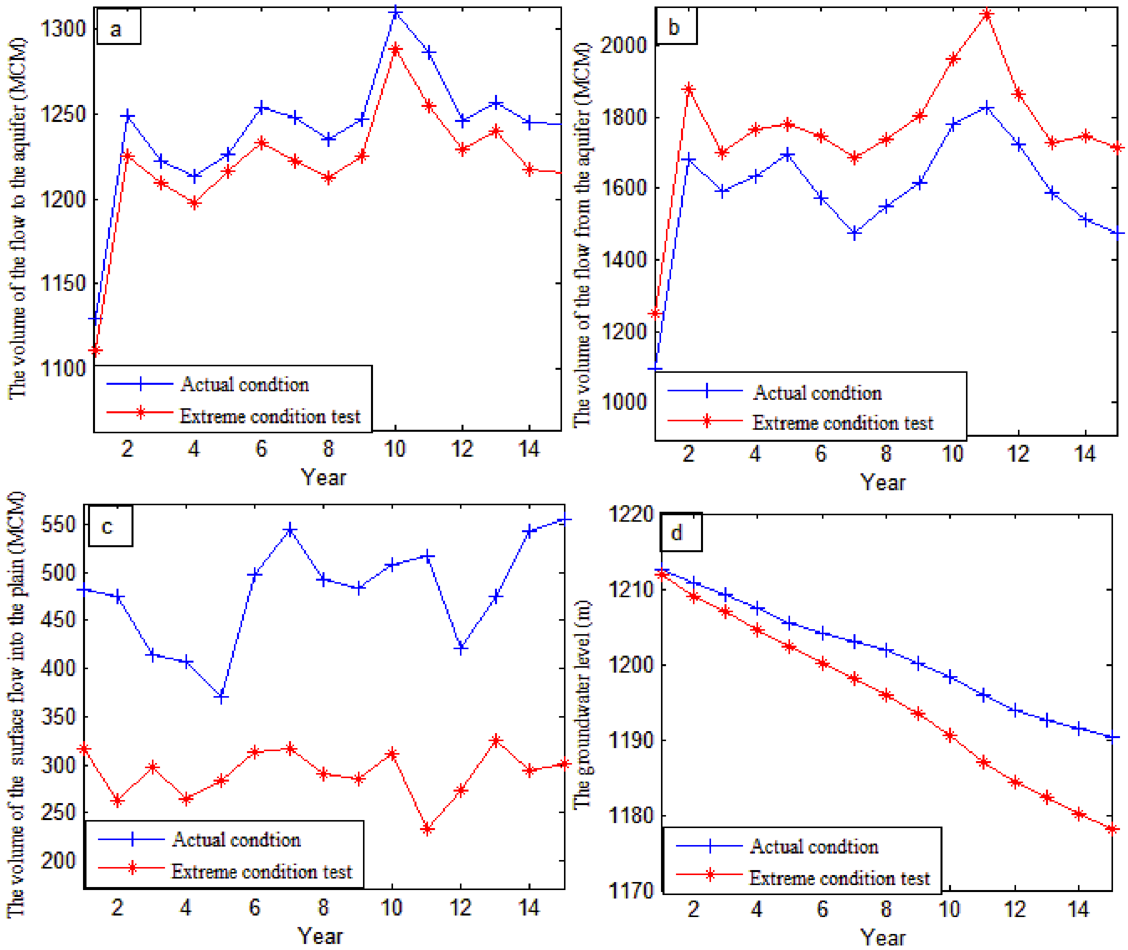


Figure 8. Verification test of SD by assuming the allocation of Taleghan dam to be zero. (a) The changes of the volume of flow into the aquifer; (b) The changes of the volume of flow from the aquifer; (c) The changes of the volume of the surface flow to the plain; (d) The changes of groundwater level

3.3. Scenarios Analysis

After the calibration and the verification of the developed model, eighteen scenarios that were mentioned in table 1 were applied separately to the model. Table 3 shows farmers' income, groundwater drawdown and normalized variables for all scenarios.

As mentioned, scenario 0 is the historical condition, where the aquifer was extremely depleted over the 15 years and according to table 3, farmers earned the maximum income of 2.49 billion dollars, therefore in this scenario, the FID was zero. Other scenarios have been evaluated based on scenario 0. Scenario 1, with a cropping pattern with no wheat, which saves groundwater with no serious impact on farmers' income. This scenario has been led to reduce the rate of the negative balance, such that the amount of drawdown would be 1.3 meters, while farmers' income only is reduced by 8.6%. Due to the wheat guaranteed purchase program of the Iranian government [12], nearly 30% of farms are cultivated by wheat despite the marginal benefit of wheat crops in this area.

In the second scenario, removing barley would cause about 214 million dollars income deficiency, but improve drawdown by as much as 6.3 meters. It shows that the farmer's income isn't noticeably affected by the removal of barley, while it can make a credible positive impact on the groundwater level. In scenarios 2, 8, 9, 10, and 11 respectively, when barley, rapeseed, sugar beets, onion, and cotton were omitted, the farmers' income diminished by less than 0.6 %, but the amount of avoided drawdown varied from 1% to 30%. Removing barley and sugar beet crops would avoid depletion by as much as 6.7 and 3.7 meters respectively. It would be less than one meter for rapeseed, onion, and cotton crops. Therefore barely has a more potential to increase drawdown when compared to the other four crops in these scenarios.

In Scenarios 3, 5, 6, 7, 12, and 17, the impact of leaving out potato, maize, silage, cucumber, rapeseed, and pistachio crops respectively, was a decrease in farmers' income from 1% to 5% and the avoided drawdown would differ from 0.48 to 4.7 meters. In these scenarios, scenario 17 could have the most impact to decrease farmers' income by about 100 million dollars, and prevent aquifer drawdown by about 0.78 meters. Scenarios 5, 6, and 12 would reduce farmers' income approximately 5.5 %, while these prevent the groundwater level from going down further; 4, 4.7 and 2.26 meters respectively.

Table 3. The amount of drawdown and farmer's net income for the scenarios over 15 years

No.	Drawdown (m)	Avoiding drawdown (m)	ADW (%)	Total farmer's net income (billion dollars)	Farmer's net income deficiency (million dollars)	FID (%)
Scenario 0	20.80	0.00	0.00	2.49	0.00	0.00
scenario 1	1.38	19.42	93.35	2.28	214.84	8.61
Scenario 2	14.54	6.27	30.12	2.49	3.76	0.15
Scenario 3	19.63	1.17	5.63	2.46	33.96	1.36
Scenario 4	16.89	3.91	18.80	2.21	281.50	11.29
Scenario 5	16.80	4.00	19.22	2.39	103.15	4.14
Scenario 6	16.02	4.78	22.98	2.36	134.32	5.38
Scenario 7	20.32	0.49	2.34	2.46	29.91	1.20
Scenario 8	20.34	0.46	2.22	2.49	4.04	0.16
Scenario 9	17.06	3.74	17.98	2.48	13.43	0.54
Scenario 10	20.56	0.24	1.16	2.49	3.81	0.15
Scenario 11	20.13	0.68	3.25	2.49	8.31	0.33
Scenario 12	18.54	2.26	10.87	2.39	107.69	4.32
Scenario 13	13.58	7.22	34.72	2.24	249.41	10.00
Scenario 14	18.75	2.06	9.89	2.35	144.09	5.78
Scenario 15	8.01	12.79	61.50	1.60	890.24	35.69
Scenario 16	18.24	2.56	12.30	2.32	171.63	6.88
Scenario 17	20.02	0.78	3.77	2.39	100.21	4.02

Removing watermelon and melon, peach and nectarine, and apple would reduce farmers' income about 5-10 **%** in scenarios 13, 14, and 16 respectively, and these prevent groundwater depletion by about 34.72%, 9.89%, and 12.30 % respectively.

Scenario 15 decreases the farmers' income dramatically by 36%. The scenario would help to reduce the historical drawdown to 8 meters. Thus, grapes play an important role for farmers' income. Due to a good price, low cost, high export, and suitable climatic and soil conditions.

3.4. Indicators Analysis

The groundwater sustainability was assessed by SUI for each scenario. The index takes a positive or negative value, where high values (which are close to one) correspond to sustainable water use, and low values (especially negative ones) show groundwater abuse. The results infer that the SUI would be negative for all scenarios except scenario 1 (Fig.9). Meaning that, if the wheat crop was removed, then more sustainable conditions would be achieved.

Consequently, we would have unsustainable groundwater use under all scenarios. The government's guaranteed price policy, has motivated farmers to plant wheat, despite its low benefit, and increased its cultivation.

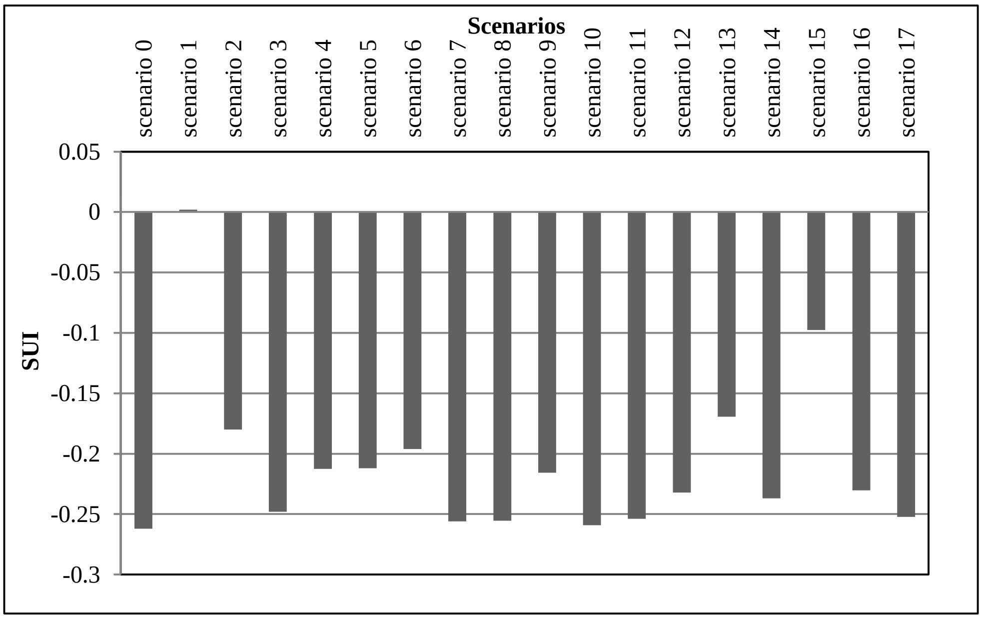


Figure 9. Average annual groundwater sustainability index (SUI) of scenarios

As mentioned before, the pressure on groundwater extraction would be presented by WEI+, so that 0-20% corresponds to no stress; values between 21% and 40% show the situation of water stress, and value higher than 40% indicates extreme stress on groundwater [21]. Figure 10 shows the result of WEI+ index for 18 scenarios. As this figure shows, although scenario 1 has the lowest WEI+ among the others, in all of them the aquifer is under severe stress. This is because the amount of groundwater extraction is much higher than the input inflow in all scenarios.

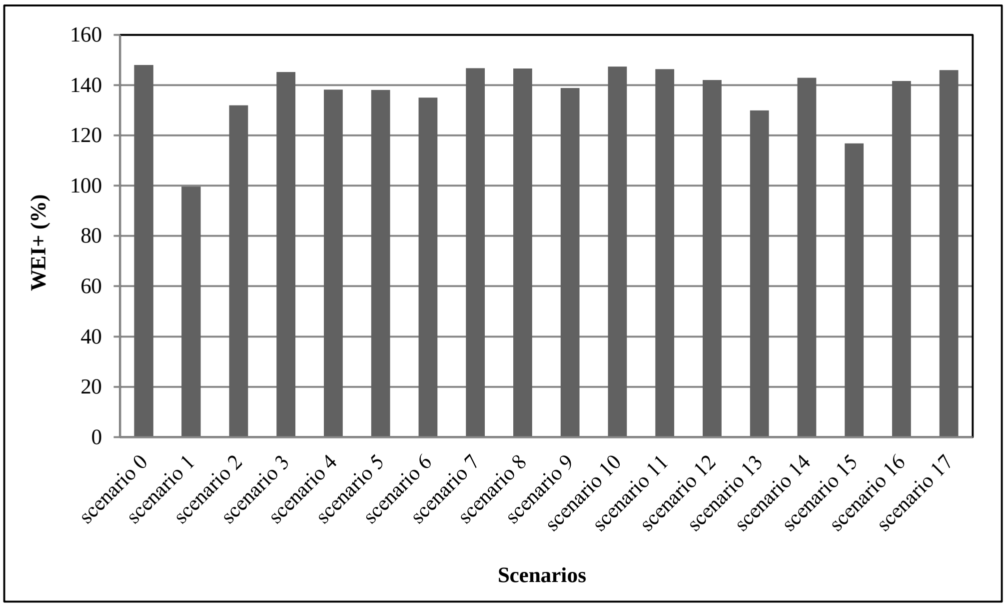


Figure 10. Average annual water exploitation index (WEI+) of scenarios

4. Conclusion

The lack of fresh water is one of the primary world issues that has affected many countries in the arid and semi-arid area, such that human life is threatened in these regions. Groundwater depletion is one of the most common tragedies in these areas, causing many villages and cities to be abandoned. Inappropriate water resource management not only has led to groundwater depletion but also increased the spread of poverty. In this research, the effect of cropping patterns on the farmers' income as well as the aquifer, on the Qazvin plain as a case study, with 1.3 yearly drawdowns, is studied using system dynamics.

The system dynamics that includes two subsystems, water volume, and farmers' income were calibrated using a simple genetic algorithm that minimized the difference between the simulated data and the observed data over 15 years, from 1997 to 2011. By removing crops one by one, 18 scenarios were developed. In each scenario, the effect of the absence of each crop on the farmer's income and the aquifer was assessed by SUI and WEI+ indicators.

The results show that wheat is the crop that has the most impact on the aquifer, such that cropping patterns with no wheat had the lowest drawdown and negligible impact on farmer's income. Further, the results show that grapes play the most important role in the economical subsystem of the case study, such that removing them would reduce the farmers' income by 36%.

Finally, increased wheat production has resulted from the government guaranteed purchase policy, even though it does not make as much money as other crops. This study revealed how the guaranteed purchase leads to groundwater depletion without any significant benefit for farmers.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Patle, G T, and D K Singh. "Sensitivity of Annual and Seasonal Reference Crop Evapotranspiration to Principal Climatic Variables." Journal of Earth System Science 124, no. 4 (June 2015): 819–828. doi:10.1007/s12040-015-0567-8.

[2] Daghighi, Amin, Ali Nahvi, and Ungtae Kim. "Optimal Cultivation Pattern to Increase Revenue and Reduce Water Use: Application of Linear Programming to Arjan Plain in Fars Province." Agriculture 7, no. 9 (September 5, 2017): 73. doi:10.3390/agriculture7090073.

[3] Iglesias, Ana, and Luis Garrote. "Adaptation Strategies for Agricultural Water Management under Climate Change in Europe." Agricultural Water Management 155 (June 2015): 113–124. doi:10.1016/j.agwat.2015.03.014.

[4] Sinha, D.K., K. M. Singh, N. AHMAD, V. P. Chahal, and M.S. Meena. "Natural resource management for enhancing farmer 's income : An optimal crop planning approach in Bihar." The Indian Journal of Agricultural Sciences 88(4) (2018): 121–126.

[5] Zeng, Xieting, Shaozhong Kang, Fusheng Li, Lu Zhang, and Ping Guo. "Fuzzy Multi-Objective Linear Programming Applying to Crop Area Planning." Agricultural Water Management 98, no. 1 (December 2010): 134–142. doi:10.1016/j.agwat.2010.08.010.

[6] Jianchang, Liu, Zhang Luoping, Zhang Yuzhen, and Deng Hongbing. "Trade-Off Between Water Pollution Prevention, Agriculture Profit, and Farmer Practice—an Optimization Methodology for Discussion on Land-Use Adjustment in China." Environmental Monitoring and Assessment 187, no. 1 (November 13, 2014). doi:10.1007/s10661-014-4104-z.

[7] Habibi Davijani, M., M. E. Banihabib, A. Nadjafzadeh Anvar, and S. R. Hashemi. "Multi-Objective Optimization Model for the Allocation of Water Resources in Arid Regions Based on the Maximization of Socioeconomic Efficiency." Water Resources Management 30, no. 3 (January 9, 2016): 927–946. doi:10.1007/s11269-015-1200-y.

[8] Varade, Smita, and Jayantilal N. Patel. "Determination of Optimum Cropping Pattern Using Advanced Optimization Algorithms." Journal of Hydrologic Engineering 23, no. 6 (June 2018): 05018010. doi:10.1061/(asce)he.1943-5584.0001655.

[9] Haouari, Mohamed, and Mohamed N. Azaiez. "Optimal Cropping Patterns Under Water Deficits." European Journal of Operational Research 130, no. 1 (April 2001): 133–146. doi:10.1016/s0377-2217(00)00028-x.

[10] Gorantiwar, S.D., and I.K. Smou. "Multilevel Approach for Optimizing Land and Water Resources and Irrigation Deliveries for Tertiary Units in Large Irrigation Schemes." Journal of Irrigation and Drainage Engineering 13(3) (2005): 264–272. doi:10.1061/(ASCE)0733-9437(2005)131:3(254).

[11] Karamouz, Mohammad, Behzad Ahmadi, and Zahra Zahmatkesh. "Developing an Agricultural Planning Model in a Watershed Considering Climate Change Impacts." Journal of Water Resources Planning and Management 139, no. 4 (July 2013): 349–363. doi:10.1061/(asce)wr.1943-5452.0000263.

[12] Boustani, Fardin, and Hamid Mohammadi. "Determination of optimal cropping pattern due to water deficit: A case study in the south of Iran." American-Eurasian Journal of Agricultural and Environmental Sciences 7, no. 5 (2010): 591-595.

[13] Jebelli, J., B. Paterson, and A. Abdelwahab. "A linear programming model to optimize cropping pattern in small-scale irrigation schemes : an application to Mekabo Scheme in Tigray , Ethiopia." International Journal of Environmental & Agricultural Research 2(8) (2016): 24–34.

[14] Fazlali, Ali, and Mojtaba Shourian. "A Demand Management Based Crop and Irrigation Planning Using the Simulation-Optimization Approach." Water Resources Management 32, no. 1 (August 4, 2017): 67–81. doi:10.1007/s11269-017-1791-6.

[15] Osama, Sara, Mohamed Elkholy, and Rawya M. Kansoh. "Optimization of the Cropping Pattern in Egypt." Alexandria Engineering Journal 56, no. 4 (December 2017): 557–566. doi:10.1016/j.aej.2017.04.015.

[16] Yousefi, Maryam, Mohammad Ebrahim Banihabib, Jaber Soltani, and Abbas Roozbahani. "Multi-Objective Particle Swarm Optimization Model for Conjunctive Use of Treated Wastewater and Groundwater." Agricultural Water Management 208 (September 2018): 224–231. doi:10.1016/j.agwat.2018.06.025.

[17] Rath, Ashutosh, Sandeep Samantaray, Sudarsan Biswal, and Prakash Chandra Swain. "Application of Genetic Algorithm to Derive an Optimal Cropping Pattern, in Part of Hirakud Command." Progress in Computing, Analytics and Networking (2018): 711–721. doi:10.1007/978-981-10-7871-2_68.

[18] Abdul Rahim, F.H., N.N. Hawari, and N.Z. Abidin. "Supply and Demand of Rice in Malaysia : A System Dynamics Approach". International Journal of Supply Chain Management 6(4) (2017): 234–240.

[19] Zulch, Gert, and Mikko Borkircher. "Flexible Work Organization in Manufacturing — A Simulation-Supported Feasibility Study." Proceedings Title: Proceedings of the 2012 Winter Simulation Conference (WSC) (December 2012). doi:10.1109/wsc.2012.6465229.

[20] Xi, Xi, and Kim Leng Poh. "Using System Dynamics for Sustainable Water Resources Management in Singapore." Procedia Computer Science 16 (2013): 157–166. doi:10.1016/j.procs.2013.01.017.

[21] Pedro-Monzonís, María, Abel Solera, Javier Ferrer, Teodoro Estrela, and Javier Paredes-Arquiola. "A Review of Water Scarcity and Drought Indexes in Water Resources Planning and Management." Journal of Hydrology 527 (August 2015): 482–493. doi:10.1016/j.jhydrol.2015.05.003.

[22] Sullivan, Caroline. "Calculating a Water Poverty Index." World Development 30, no. 7 (July 2002): 1195–1210. doi:10.1016/s0305-750x(02)00035-9.