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Cropping Pattern Optimization Using System Dynamics Approach and Multi-Objective Mathematical Programming

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ABSTRACT

To determine the optimum cropping pattern for Kermanshah Plain, Iran, a dynamic model was developed in Vensim PRO x32 software to simulate the actual situation in the region. Stochastic simulation of time series method was used to predict the values of climate parameters in the future. After ensuring the performance of the dynamic model as well as time series model, optimization process of crop pattern was performed using the existing optimization tool in Vensim PRO x32 software in addition to multi objective mathematical programming approach by Powell method in three different scenarios. The objective functions included maximizing the economic benefit for farmers and minimizing the extracted water from aquifer. The results showed that ratio of the gained benefit to the amount of water extracted from the wells in optimized conditions was always higher than the current conditions. The value of this ratio for the three scenarios was 1.23, 0.89, and 0.94, respectively, which in all three scenarios were higher than the current value (0.68). The results showed that in the scenario in which changes in the crop coefficients of all crops are possible, in order to optimize the cropping pattern, the area allocated to wheat, barley, grain and forage maize, tomato, clover, and onion should be decreased in the current cropping pattern. Furthermore, the results of optimization indicated an increase in the area under cultivation of saffron, rose, greenhouse, medicinal plants, and olive, compared to the current conditions.

Keywords: Objective functions, Optimizer tool, Powell method, Vensim PRO x32.

INTRODUCTION

Due to the rapid change in population and urbanization, land and water resources are becoming very limited. Consequently, cropping pattern optimization has received extensive attention in recent years (Osama *et al*., 2017). The decision maker's purpose in selecting an optimum cropping pattern does not usually limit to a specific subject. The decision maker needs to achieve a balance between gained outcomes related to the decision that are in contradiction with each other. Decision making under a situation in which there are several specific objectives facing agricultural managers, in addition to use of decision making tool, requires numerous data. Designing a mechanism for a management system based on the desired data and multiple objectives over time is not an easy matter (Jones and Barnes, 2000). In this regard, applying the mathematical programming in order to provide an optimum crop pattern has significant advantages. One of the advantages of utilizing the multi objective programming approach is the possibility of considering different objectives in the process of modeling as well as achieving compromise between the mentioned objectives according to the existing

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constraints (Berbel and Gomez-Limon, 2000; Francisco and Mubarik, 2006). Many scholars in their studies have examined cropping pattern optimization in a given study area using linear or nonlinear mathematical programming in the form of single or multi objective (Keramatzadeh *et al*., 2011; Ziaee *et al*., 2014; Adekanmbi and Olugbara, 2015; Gurovich and Oyarce, 2015; Shreedhar *et al*., 2015; Srivastava and Singh, 2015; Ghasemi *et al*., 2016; Jebelli *et al*., 2016; Daghighi *et al*., 2017; Osama *et al*., 2017; Hao *et al*., 2018; Varade and Patel, 2018; Rajabi *et al*., 2019).

In general, it seems essential to use a general and systemic approach for integrated management of water resources and providing proper management strategies, including determining the optimum cropping pattern. The systematic approach claims to provide a method for a more principled approach to complex issues. The system is meant to be a collection of components working together as a whole. Many researchers have used system dynamics approach to assess the effects of applying different crop patterns on the water resources status in their studies (Elmahdi *et al*., 2004, 2006; Cui *et al*., 2009; Lehtonen *et al*., 2014; Mesgari and Jabalameli, 2017).

The mentioned studies have revealed that optimization of cropping pattern using system dynamics approach has been carried out only in a small number of researches. Elmahdi *et al*. (2005) developed a dynamic model in Vensim software environment in order to determine the optimum crop pattern with two objectives including maximizing the net benefit and minimizing the water required for irrigation. Afterwards, they linked a linear programming mathematical algorithm to the dynamic model, and carried out the optimization process. In addition, they performed the optimization process by a commercial linear programming solver. They found that both optimization methods reflected the same results. The researchers stated that applying Vensim software along with an optimization algorithm could be an appropriate tool for optimizing water resource issues. Sharma *et al*. (2010) developed a dynamic nonlinear programming model in order to determine the optimum cropping pattern to maximize economic profit in the Himalayan Region, India. They ran the mentioned model under various management scenarios using the GAMS software and determined the optimum cropping pattern.

In spite of the mentioned points, only one research has been performed about optimization of the cropping patterns using the optimization tool existing in Vensim PRO x32 software in the past years. This research was performed by Nozari and Mohseni (2015) in Iran and published in an Iranian Journal in Persian Language. However, because of its importance in using Vensim optimizer and similar research methodology with this study, it is presented here. In this research, cropping pattern of Right Abshar Irrigation and Drainage Network in Isfahan, Iran, has been optimized using optimizer tool of Vensim software. The researchers considered two objective functions including maximizing income-to-cost ratio and minimizing groundwater extraction. They optimized the cropping pattern in both modes of paying attention and not paying attention to conserve the total area of crops cultivated in the base year. They examined scenarios based on limit of the amount of changes in crop cultivation area in the range of 10, 20, 30, 40, and 50% higher and lower than their values in the base year. The researchers stated that the existing cropping pattern was very different from the optimal cropping pattern.

A review of the carried out researches showed that no integrated management study has been conducted yet on Kermanshah Plain's water resources considering system dynamics approach in order to optimize the cropping pattern. For this purpose, in the current study, we aimed to develop a model that is able to comprehensively cover the effective components of Kermanshah Plain's water resources. One of the most important components in this respect is the cropping pattern. Therefore, in this study, its optimization has been considered. To this end, the components affecting the status of water resources in Kermanshah Plain were defined as an interconnected system in Vensim PRO x32 software. Then, optimization process of the cropping pattern was performed using the optimization tool in the software applying a multi objective mathematical programming approach using the Powell method (Fletcher and Powell, 1963). It should be noted that in this research, stochastic simulation of time series has been used in order to predict the values of future climate parameters and to use them for determining the optimum cropping pattern in the future periods.

MATERIALS AND METHODS

Study Area

Kermanshah Province, with an area of about 25,000 km^2 is located in the west of Iran. There are several plains in this province which are named "study areas" based on sub-basins. Kermanshah Province includes 33 study areas as shown in Figure 1. According to this figure, parts of some study areas are located outside the border of the province (blue border). In this research, Kermanshah study area, shown in Figure 1 by green color, was selected. The study area of Kermanshah with an area of 1,985.73 km^2 is a part of Karkheh Basin. The geographic coordinates of this study area cover from the longitudes of 46° 45´ 29” to 47° 29´ 02” east and the latitudes of 34° 06´ 40” to 34° 42´ 22” north. Considering the changes in temperature, evapotranspiration, and the amount of atmospheric precipitation, it can be considered as a relatively humid area. In this research, Kermanshah plain (with area 779.96 km2) which is located within the Kermanshah study area (with area 1985.73 km2and shown in Figure 1 by green color) has been studied. This plain is surrounded by heights. In other words, Kermanshah study area includes the Kermanshah plain and the surrounding heights.

System Dynamics Model

System dynamics model for the agricultural sector in the study area is shown in Figure 2, which consists of three parts "a", "b" and "c". Part "a" includes components related to Gavshan Dam, part "b" includes components related to the wells, crop pattern and irrigation requirement, and part "c" includes components related to the benefit of agricultural products. The model has various components as described below. To calculate each of the defined variables in the model, specific equations and formulas are used. It should be noted that some of the variables defined in the model are time series and their time distribution is considered when connecting variables to each other. It should be noted that in this study, the dynamic model is provided in Vensim PRO x32 software. This version of Vensim software includes an optimization tool, which is used to optimize the crop pattern in this research.

Modeling of Water Supply Resources for Agriculture

Sources of water supply for agriculture sector in the study area include supplied water from Gavshan Dam, effective rain, and water extracted from aquifer by agricultural wells as described below. The total water supply resources required for agriculture are defined in a variable called "Total Supply" and the percentage of irrigation requirement supply for cropping pattern is defined in a variable called "Supply Percent", which can be seen in the top of Figure 2-b.

Gavshan Dam

The volume of water in the Gavshan Dam Reservoir is defined as a rectangular storage variable and is named "Gavshan Dam" in Figure 2-a. Variables affecting the available volume of water in the dam reservoir include inflow water into the dam (Inflow), the river environmental requirement (Environmental Demand Volume), evaporation from the dam (Evaporation Volume), supply of water requirement for Bilevar Irrigation and Drainage Network (Bilevar Network Demand), minimum volume of stored water in the dam including its dead storage volume in addition to drinking water requirement storage (Minimum Volume), supplying drinking water of Kermanshah City (Drinkable Water), providing water requirement of Irrigation and Drainage Network of Miandarband in Kermanshah (Miandarband Network Demand), and finally, overflow during flood events (Spillway). It should be noted that Bilevar Irrigation and Drainage Network is outside the aquifer of the study area. However, since it is one of the components of water consumption in Gavshan Dam, calculations of

Table 1. Current cropping pattern in Kermanshah Plain.

Number	Crop	Percentage of covered area	Number	Crop	Percentage of covered area
1	Wheat	40.93	20	Greenhouse	0.10
2	Grain maize	26.82	21	Soybean	0.09
3	Barley	13.46	22	Walnut	2.94
4	Forage maize	3.76	23	Grape	0.82
5	Alfalfa	1.41	24	Apple	0.66
6	Tomato	1.13	25	Almond	0.40
7	Canola	1.13	26	Peach	0.28
8	Clover	0.94	27	Nectarine	0.19
9	Sugar beet	0.94	28	Apricot	0.15
10	Watermelon	0.66	29	Plum	0.08
11	Sunflower	0.47	30	Medicinal Plants	0.07
12	Potato	0.38	31	Rose	0.06
13	Onion	0.38	32	Cherry	0.05
14	Cantaloupe	0.38	33	Olive	0.03
15	Cucumber	0.28	34	Pear	0.03
16	Vegetable	0.28	35	Saffron	0.03
17	Faba bean	0.28	36	Quince	0.02
18	Pea	0.19	37	Sour cherry	0.01
19	Bean	0.19			

Figure 1. Study areas in Kermanshah Province (Kermanshah study area: Green, Other study areas: Beige, Province boundary: Blue line).

water requirement of cropping pattern concerning this network has also been considered in the right side of Figure 2-a. In this study, the amount of environmental demand volume in the Montana Method are considered for a relatively fair condition (Tennant, 1976). The volume of evaporated water from the reservoir was obtained by multiplying the reservoir surface area by the amount of evaporation depth from the reservoir surface obtained from evaporation pan data. The reservoir surface area was determined using reservoir surface area-storage curve which has been plotted in the "Surface Area -Storage Curve" variable. In this curve, based on the available information, for each reservoir storage,

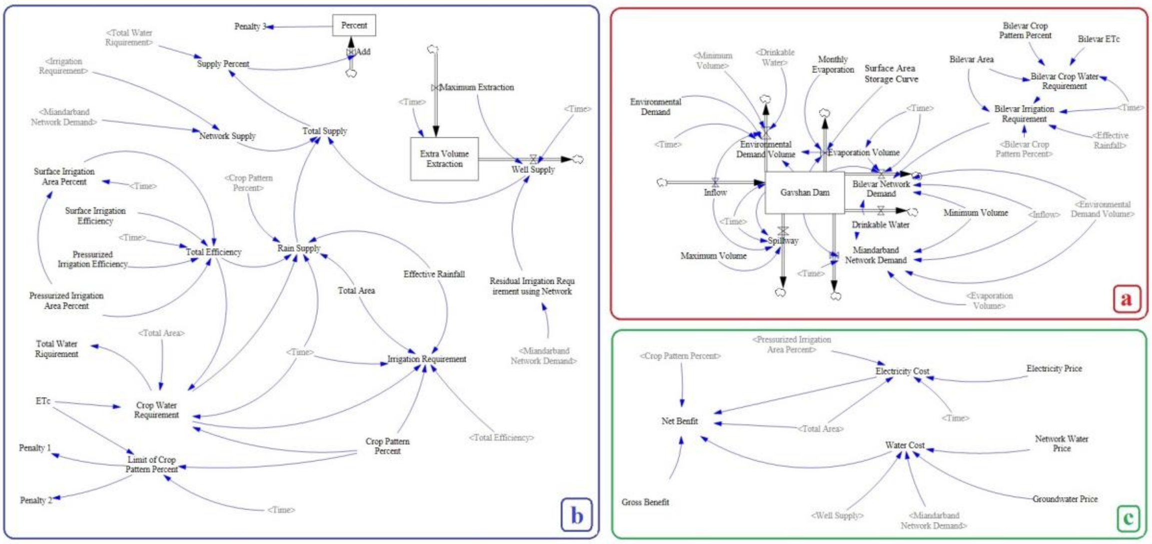

Figure 2. Schematic of the defined dynamic model for agriculture sector in the study area.

the reservoir surface area was determined. It should be mentioned that Gavshan Dam has supplied a portion of the irrigation requirement of Miandarband Region located in the study area since 2011. However, due to lack of proper management, the majority of farmers, in addition to having water from the dam, extract water from the aquifer at the same amount as before.

Agricultural Wells

The volume of extra water extracted from the aquifer through agricultural wells is defined as a rectangular storage variable called "Extra Volume Extraction" in the right side of Figure 2-b. In this section, maximum amount of water extracted by the wells (Maximum Extraction) is defined as the input variable and the amount of water required to fulfill agricultural needs (Well Supply) is output variable.

Effective Rain

The variable "Rain Supply" is included as one of the water supply sources needed for agriculture sector. The volume of this variable is affected by the variables of "Effective Rainfall", "Total Area", "Crop Pattern Percent", "Total Efficiency" and "Crop Water Requirement" considering irrigation efficiency that is shown in Figure 2-b.

Modeling of Irrigation Methods

On the left side of Figure 2-b, variables such as "Surface Irrigation Area Percent", "Pressurized Irrigation Area Percent", "Surface Irrigation Efficiency", "Pressurized Irrigation Efficiency" and "Total Efficiency" are seen. The values of these variables affect the amount of required water for cropping pattern of the region. It should be noted that in this study, owing to development of pressurized irrigation systems, the percentage of area covered by pressurized irrigation systems was increased annually during the simulation period.

Modeling of Cropping Pattern and Water Requirement

Some variables including crop Evapotranspiration (ETc), water requirement of cropping pattern considering the irrigation efficiency and effective rainfall (Irrigation Requirement), and the percentage of covered area by each plant in the cropping pattern (Crop Pattern Percent) are defined in the bottom of Figure 2-b.

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Modeling of Net Benefit

The effective variables on the "Net Benefit" variable are defined in Figure 2-c. In the "Gross Benefit" variable, the gross benefit amounts according to cultivation of each hectare of plants were set without taking the water and electricity costs into account. Water and electricity costs are also defined in variables of "Water Cost" and "Electricity Cost", respectively. The average electricity consumption cost per hectare is defined in the "Electricity Price" variable. The price of each Million Cubic Meters (MCM) of water delivered to the irrigation and drainage network is defined in "Network Water Price" variable. Moreover, the price of each MCM of groundwater extracted for agricultural consumption is defined in the "Groundwater Price" variable. According to the relationship defined in the "Water Cost" variable, the price of groundwater will be merely applied if the extraction of groundwater is greater than the permissible limit (specified by the Regional Water Company in the study area).

Modeling of Optimization Constraints

Three variables, namely, "Penalty 1", "Penalty 2" and "Penalty 3" are defined in Figure 2-b, in order to exert the penalties over the objective function in case of failure to meet the desired constraints in solving the optimization problem. The "Penalty 1" and "Penalty 2" variables, in the left bottom of Figure 2-b, are influenced by the "Limit of Crop Pattern Percent" variable, which calculates the total crop percentage in the cropping pattern. Since one of the constraints defined in this study is that total optimized area is equal to total current cultivation area, the total crop coefficients in the optimum cropping pattern should be equal to 1. The "Penalty 1" and "Penalty 2" variables are defined so that if values are less or more than 1 in the “Limit of Crop Pattern Percent” variable, a penalty is imposed on the objective function and exits it from the maximum state. In other words, if the constraint is not met, the penalty values are deducted from the objective function value. Another constraint defined in this study is that the percentage of water requirement supplied for plants should not be less than 80%. Therefore, the "Penalty 3" variable in the top of Figure 2-b, is defined in a way that in case of creating the numbers less than 80 in the "Percent" variable, a penalty will be imposed on the objective function and exits from the maximum mode.

Time Series Model

Since one of the objectives of this study is to investigate the status of the aquifer in the future, climatic parameters should be predicted in the upcoming years. The study of water cycle in large scales such as basin areas is a complex problem that requires identification, estimation, and modeling of all interacting processes. For this reason, hydrological processes are always known as stochastic processes. Therefore, stochastic models should be used to model the hydrological processes. Stochastic simulation of time series related to water resources, especially hydrological time series, has been widely used to solve problems of water systems planning and management in recent decades. In this study, in order to predict the values of parameters such as precipitation, evaporation, potential Evapotranspiration (ET0), and river discharge, the data of the past 30 years (1986-2016) were used. After fitting the appropriate time series model, the future values of these parameters were predicted for the next 10 years (2016-2026). Matching the time series model on the desired parameters and predicting the values of these parameters in the future was made in SAMS (Stochastic Analysis Modeling and Simulation) software. To do this, the following steps were taken:

1- Investigating the trend of changing values of the parameters using modified Mann-Kendall test with elimination of entire effects of autocorrelation (Hamed and Rao, 1998).

2- Initial evaluation of the parameters’ values including independence and static, homogeneity, normality, and standard data.

3- Modeling of parameters’ values using PARMA (Periodic Auto Regressive Moving Average) linear models.

4- Checking accuracy of the selected model and then forecasting the values of parameters for 10 years.

Optimization

In this study, the optimum cropping pattern was determined according to the climatic conditions of the next 10 years (2026) in the following three scenarios:

1. There will be a possibility of change in the area covered by all plants in the cropping pattern.
2. The area covered by the wheat will not change.
3. The area covered by wheat as well as gardens will not change.

Objective Functions

In this research, two objective functions were considered for defining the optimization problem. The variables in the equations were previously defined in the dynamic model description. It should be noted that "aRow" phrase in the following equations is a subscript that is defined in the dynamic model in order to include all 37 cropping pattern plants in the "ETc" variable. In the defined equations for the objective functions, the negative sign represents minimizing, the positive sign represents maximizing and the number after "/" is used to magnify the values of desired variable in order to match with magnitude of the values of other objective variables. In this research, values of the "Net Benefit" variable were considered as the basis and values of other objective variables were accordingly increased. It should be noted that in definition of the objective functions in Vensim PRO x32 software, the "/" sign means multiplying the value of the desired variable by the number after the sign.

1- Minimizing the amount of water extracted from wells ("Well Supply" variable)

$$Well\ \ Supply\ \ / -1000 \tag{1}$$

In this equation:

$$\begin{aligned} &Well\ Supply = IF\ THEN\ ELSE(\ Maximum\ Extraction\ (IF\ THEN\ ELSE \\ &(MODULO(Time,12\ ) = 0,12\ , MODULO(Time,12\ )\ )) >= Residual \\ &Irrigation\ Requirement\ using\ Network, Residual\ Irrigation \\ &Requirement\ using\ Network, Maximum\ Extraction\ (IF\ THEN\ ELSE \\ &(MODULO(Time,12\ ) = 0,12\ , MODULO(Time,12\ )\ ))\ ) \end{aligned} \tag{2}$$

2- Maximizing the net benefit ("Net Benefit" variable)

$$Net\ \ Benefit\ \ /\ 1 \tag{3}$$

In this equation:

$$\begin{aligned} &Net\ Benefit\ = (sum(Crop\ \ Pattern\ \ Percent[aRow!\ ] * Gross\ Benefit[aRow!\ ]) \\ &* Total\ \ Area - Electricity\ Cost - Water\ \ Cost)/12 \end{aligned} \tag{4}$$

Constraints

Defined constraints of the optimization problem in this research include the followings:

1. Optimized area must be equal to the current cultivation area. Therefore, if r1 to r37 are considered as the crop coefficients of each of the 37 plants in the crop pattern, sum of the coefficients will be equal to 1. As mentioned previously, the Penalty 1 and Penalty 2 variables are defined in the dynamic model so that in the case of creating values less or more than 1 for sum of the crop coefficients in the "Limit of Crop Pattern Percent" variable, a penalty is imposed on the objective function and exits it from the maximum state. The defined equations for the "Limit of Crop Pattern Percent", "Penalty 1" and "Penalty 2" variables in the dynamic model are as follows.

$$\begin{aligned} &Limit\ \ of\ Crop\ \ Pattern\ \ Percent = sum(IF\ \ THEN\ \ ELSE(ETc[a\ Row!\ ](Time) \\ &> 0,1\ ,0\ ) * Crop\ \ Pattern\ \ Percent[aRow!\ ]) \end{aligned} \tag{5}$$

$$Penalty\ \ 1 = IF\ \ THEN\ \ ELSE(Limit\ \ \ of\ \ Crop\ Pattern\ \ \ Percent\ \ < 1,1\ ,0\ ) \tag{6}$$

$$Penalty\ \ 2 = IF\ \ THEN\ \ ELSE(Limit\ \ \ of\ \ Crop\ Pattern\ \ \ Percent\ \ > 1,1\ ,0\ ) \tag{7}$$

In optimum state, the values of penalty variables in the 12 months of the year must be minimum. For this purpose, the following equations were defined as objective in the optimization problem. It should be noted that in optimization process using the optimizer tool in Vensim PRO x32 software, some constraints must inevitably be defined as objective functions. This method is used to define penalty variables in this study.

$$Penalty\ \ 1\left[12\right]/ -10000 \quad (8)$$

$$Penalty\ \ 2\left[12\right]/ -10000 \quad (9)$$

2. In order to perform the optimization operation, the lower and upper permissible limit values of r1 to r37 should be defined for the model. Since cultivation of some plants in each region may have a strategic aspect and some of the plants are also cultivated in order to satisfy needs of their own region, in this study, the lower permissible limit value for no crop coefficient is considered equal to zero. Moreover, allocation of the whole surface to one or more specific crop and removal of other crops is not practically feasible, so, none of the permissible upper limits related to crop coefficients is considered equal to 1. In this research, lower and upper permissible limit values of crop coefficients are determined in such a way that after optimization operation, sum of the optimized coefficients would be equal to 1. For example, to define constraint of the lower and upper permissible limits of the crop coefficients in the case of change in the area covered by all plants in the cropping pattern is possible, Equation (10) is used.

$$0 < Crop\ \ Pattern\ \ Percent\left[aRow\right] \leq 0.0539 \quad (10)$$

3. The optimum amounts of crop coefficients in the crop pattern should be determined in a way that the percentage of water requirement supply related to the crop pattern would be more than 80%. As was mentioned before, the "Penalty 3" variable in the dynamic model is defined in a way that in the case of producing values less than 80 for supplying percentage of the plant's water requirement, a penalty will be exerted on the objective function to remove it from the maximum state. The defined equation for the "Penalty 3" variable in the dynamic model is shown in Equation (11). In this equation, the "Percent" variable contains the cumulative values of the "Supply Percent" variable and the term "GET TIME VALUE (0,0,0)" means the number of month for any cumulative value.

$$Penalty\ \ 3 = IF\ \ THEN\ \ ELSE((Pe\ \ rcent / GET\ \ TIME\ \ VALUE(0\ \ ,0,0)) < 80,1,0\ ) \quad (11)$$

In optimum state, the values of "Penalty 3" variable at 12 months of the year must be minimum. For this purpose, the following equation was defined as objective in optimization problem.

$$Penalty\ \ 3\left[12\right]/ -10000 \quad (12)$$

RESULTS AND DISCUSSION

Assessment of Dynamic Model

After preparing the dynamic model, several tests should be taken to ensure that the model functions properly. In this study, equations defined for the relationship of variables with each other, calculated values of variables by the model and their dimensional compatibility were examined. Moreover, extreme conditions test was performed on the model. In this test, by changing the inputs and assigning them to zero, accuracy of the model's function can be examined. For example, by assigning the Evapotranspiration (ETc) values of crop pattern to zero, the values of irrigation requirements and total required water supply (Total Supply) will also be zero. For quantitative evaluation of error values calculated by the model against observed values, the coefficient of determination and error percentage rate were calculated. Figure 3 shows the correlation between calculated and observed values for the reservoir volume of Gavshan Dam during 2012-2013. As can be seen, the coefficient of determination is approximately equal to 0.98. Furthermore, based on the obtained results, the calculated error rate during this period was always less than ±2%. High coefficient of determination and low computational error percentage indicate the validity of model for simulating the real system.

Evaluation of Time Series Model

In modeling the studied meteorological parameters values on a monthly scale, examining the selected models showed that the prevailing

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Table 2. The mean annual values of root mean square error and Nash-Sutcliffe statistics for each of the studied meteorological parameters in both modes of instruction and examination. [a]

Parameter	Root mean square error		Nash-Sutcliffe	
	Instruction	Examination	Instruction	Examination
Precipitation	1.68	1.41	0.91	0.85
Evaporation	10.98	10.28	0.72	0.85
ET0	0.19	0.17	0.65	0.48
Q1	0.36	0.35	0.96	0.90
Q2	1.80	1.24	0.62	0.83
Q3	1.35	1.17	0.66	0.72

[a] Q1, Q2 and Q3" are river discharge in three hydrometry stations in the study area.

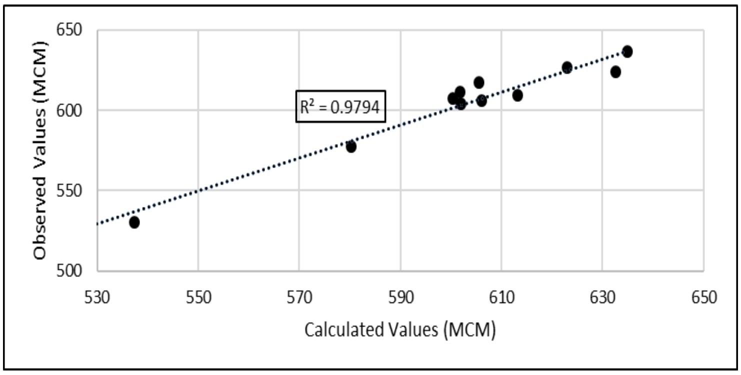

Figure 3. Correlation between calculated and observed values for the reservoir volume of Gavshan Dam during 2012-2013.

model for monthly rainfall, evaporation, potential evapotranspiration, and river discharge data was PARMA (1,0) model. In order to investigate the model accuracy, root mean square error statistic was utilized, and the model efficiency was evaluated by the Nash-Sutcliffe statistic. In Table 2, the mean annual values of root mean square error and Nash-Sutcliffe statistics for each of the studied parameters are presented in both modes of instruction and examination. Results indicated that accuracy and efficiency of the selected models in modeling the desired parameters were acceptable. It should be noted that the river discharge parameter was considered in three separate rivers, which were introduced as Q1, Q2, and Q3.

The diagrams presented in Figures 4 to 9 show variations in precipitation, evaporation, potential evapotranspiration, and river discharge, respectively, over 480 months (360 months for 30-year statistical data in time series modeling, and 120 months for predicting the parameters in the next 10 years).

Results of Cropping Pattern Optimization

Scenario 1: There will be a possibility of change in the area covered by all plants in the cropping pattern

In this scenario, the optimization process is carried out in such a way that it is possible to change the crop coefficients of all plants. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 1 is presented in Table 3. Results showed that in this case of optimization, the percentages of cultivation related to wheat, grain and forage maize, barley, tomato, clover, and onion are reduced. According to the defined objective functions, cultivation percentage of the plants that have high water consumption, and yet, low profitability compared to other plants, has been reduced. The cultivation percentage of other

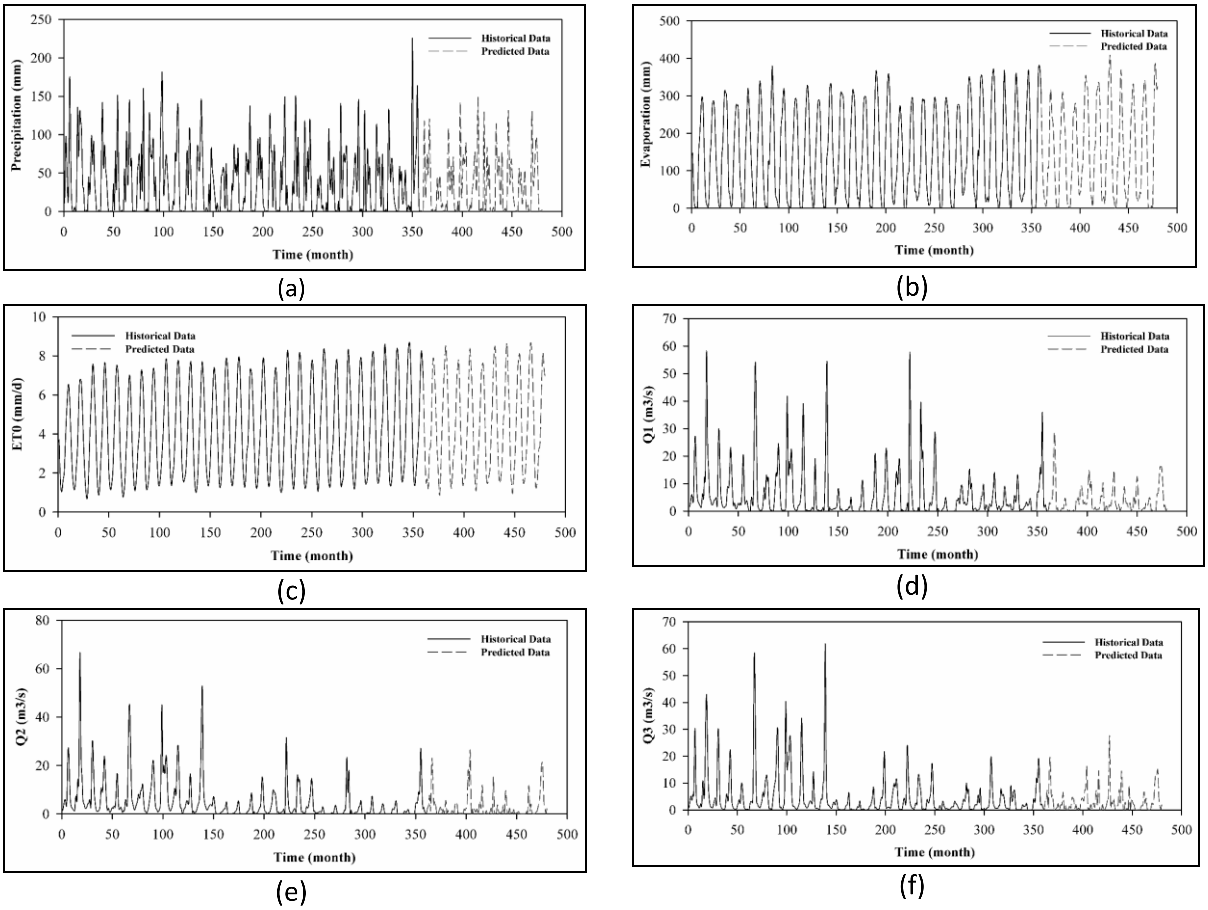

Figure 4. Variations in historical and (a) Predicted precipitation; (b) Predicted evaporation; (c) Predicted potential Evapotranspiration (ET0); (d) Predicted Q1; (e) Predicted Q2 and, (f) Predicted Q3 over a period of 480 months. "Q1, Q2 and Q3" are river discharge in three hydrometry stations in the study area.

plants has also been increased. The greatest increase of cultivation areas were allocated to sour cherry, quince, olive, pear, saffron, cherry, rose, greenhouse, plum, and medicinal plants, respectively. Cultivation of the mentioned plants will provide more benefits in return for the amount of permissible water consumption. Furthermore, based on the obtained results, the supply percentage of crop water requirement in optimized conditions is approximately 85%, which indicates implementation of the third constraint defined in the optimization problem. Results also revealed that the ratio of the gained benefit to extracted water amount from wells for the current conditions versus optimized conditions were 0.68 and 1.23, respectively, demonstrating the advantage of the optimized condition over the current condition.

Scenario 2: The area covered by wheat will not change

Since wheat is considered a strategic cultivation in the studied area, and based on the current policies as well, there is practically no possibility for reducing its cultivation area. Therefore, in this case, optimization is carried out in such a way that there is no possibility for changing the wheat crop coefficient. However, the crop coefficients of other plants can be changed. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 2 are presented in Table 4. As can be observed, the area of wheat crop has not

Table 3. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 1.[a]

Crop	Current percentage	Optimized percentage	Relative change in cultivating area
Wheat	40.93	5.26	(-) 0.13
Grain maize	26.82	0.56	(-) 0.02
Barley	13.46	2.16	(-) 0.16
Forage maize	3.76	3.38	(-) 0.90
Alfalfa	1.41	3.90	(+) 2.76
Tomato	1.13	0.09	(-) 0.08
Canola	1.13	4.31	(+) 3.82
Clover	0.94	0.89	(-) 0.94
Sugar beet	0.94	5.28	(+) 5.61
Watermelon	0.66	1.77	(+) 2.69
Sunflower	0.47	3.31	(+) 7.04
Potato	0.38	2.71	(+) 7.20
Onion	0.38	0.11	(-) 0.30
Cantaloupe	0.38	4.33	(+) 11.51
Cucumber	0.28	1.57	(+) 5.54
Vegetable	0.28	1.17	(+) 4.13
Faba bean	0.28	0.39	(+) 1.38
Pea	0.19	2.04	(+) 10.86
Bean	0.19	3.83	(+) 20.33
Greenhouse	0.10	4.16	(+) 41.58
Soybean	0.09	1.12	(+) 11.87
Walnut	2.94	4.82	(+) 1.64
Grape	0.82	2.57	(+) 3.13
Apple	0.66	1.04	(+) 1.58
Almond	0.40	4.42	(+) 11.15
Peach	0.28	1.13	(+) 3.99
Nectarine	0.19	1.49	(+) 7.92
Apricot	0.15	1.27	(+) 8.69
Plum	0.08	3.11	(+) 37.46
Medicinal plants	0.07	2.24	(+) 33.08
Rose	0.06	4.48	(+) 75.71
Cherry	0.05	4.48	(+) 98.08
Olive	0.03	5.06	(+) 149.67
Pear	0.03	3.91	(+) 140.09
Saffron	0.03	2.71	(+) 106.80
Quince	0.02	2.56	(+) 159.16
Sour cherry	0.01	2.39	(+) 187.96

[a] The mark (-) means decrease and (+) means increase. The table numbers are rounded.

been altered. Results of the study demonstrated that in this optimization scenario, the cultivation percentages related to grain and forage maize, barley, tomato, clover, onion, faba bean, and apple have been decreased, however, the cultivation percentages of other crops have been increased. The greatest area under cultivation in this case is similar to the first one. Based on the obtained results, the supply percentage of water requirement of crops in the optimized conditions is approximately 92%, which indicates implementation of the third constraint defined in the optimization problem. In addition, the results showed that ratio of the derived benefit to the amount of water extracted from the wells for the current conditions and optimized conditions were, respectively, 0.68 and 0.89. This fact similarly indicates the superiority of the optimized state compared to the current state.

Scenario 3: The area covered by wheat as well as gardens will not change.

Concerning wheat cultivation in the studied area, in addition to being strategic and the impossibility of reducing the area under cultivation, reducing the area under cultivation of

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Table 4. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 2.[a]

Crop	Current percentage	Optimized percentage	Relative change in cultivating area
Wheat	40.93	40.93	(*) 1.00
Grain maize	26.82	0.35	(-) 0.01
Barley	13.46	1.34	(-) 0.10
Forage maize	3.76	2.10	(-) 0.56
Alfalfa	1.41	2.43	(+) 1.72
Tomato	1.13	0.06	(-) 0.05
Canola	1.13	2.69	(+) 2.38
Clover	0.94	0.55	(-) 0.59
Sugar beet	0.94	3.29	(+) 3.50
Watermelon	0.66	1.10	(+) 1.67
Sunflower	0.47	2.07	(+) 4.39
Potato	0.38	1.69	(+) 4.49
Onion	0.38	0.07	(-) 0.19
Cantaloupe	0.38	2.70	(+) 7.17
Cucumber	0.28	0.98	(+) 3.46
Vegetable	0.28	0.73	(+) 2.57
Faba bean	0.28	0.24	(-) 0.86
Pea	0.19	1.27	(+) 6.77
Bean	0.19	2.38	(+) 12.67
Greenhouse	0.10	2.59	(+) 25.92
Soybean	0.09	0.70	(+) 7.40
Walnut	2.94	3.01	(+) 1.02
Grape	0.82	1.60	(+) 1.95
Apple	0.66	0.65	(-) 0.98
Almond	0.40	2.76	(+) 6.95
Peach	0.28	0.70	(+) 2.49
Nectarine	0.19	0.93	(+) 4.94
Apricot	0.15	0.79	(+) 5.42
Plum	0.08	1.94	(+) 23.35
Medicinal plants	0.07	1.40	(+) 20.62
Rose	0.06	2.79	(+) 47.20
Cherry	0.05	2.79	(+) 61.14
Olive	0.03	3.16	(+) 93.30
Pear	0.03	2.44	(+) 87.33
Saffron	0.03	1.69	(+) 66.58
Quince	0.02	1.59	(+) 99.22
Sour cherry	0.01	1.49	(+) 117.17

[a] The mark (-) means decrease, (+) means increase and (*) means unchanged. The table numbers are rounded.

gardens also does not seem to be practical. Moreover, due to high water requirements of gardens as well as critical conditions of the water resources status in the studied region, policy of increasing the gardens area seems unlikely by agricultural authorities. Hence, in this scenario, the optimization is performed in such a way that there is no possibility for changing the crop coefficients of wheat and gardens, but the crop coefficients of other plants can be changed. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 3 are presented in Table 5, which shows that the percentage of wheat and gardens did not change. The obtained results of study in this optimization scenario showed that the cultivation percentage of crops including grain and forage maize, barley, and clover decreased and cultivation percentage of other plants increased. The maximum increase in the cultivation area in this optimization scenario is allocated to soybean and greenhouse. According to the obtained results, the percentage of water supply for crop water requirement in an optimized state is

Table 5. The current percentage, optimized percentage, and relative change in cultivating area for Scenario 3.[a]

Crop	Current percentage	Optimized percentage	Relative change in cultivating area
Wheat	40.93	40.93	(*) 1.00
Grain maize	26.82	1.59	(-) 0.06
Barley	13.46	2.86	(-) 0.21
Forage maize	3.76	0.87	(-) 0.23
Alfalfa	1.41	3.89	(+) 2.76
Tomato	1.13	2.27	(+) 2.01
Canola	1.13	4.21	(+) 3.73
Clover	0.94	0.65	(-) 0.69
Sugar beet	0.94	2.42	(+) 2.58
Watermelon	0.66	4.22	(+) 6.41
Sunflower	0.47	2.13	(+) 4.54
Potato	0.38	1.59	(+) 4.23
Onion	0.38	1.17	(+) 3.12
Cantaloupe	0.38	4.30	(+) 11.41
Cucumber	0.28	3.42	(+) 12.10
Vegetable	0.28	3.50	(+) 12.41
Faba bean	0.28	1.63	(+) 5.78
Pea	0.19	1.65	(+) 8.74
Bean	0.19	2.63	(+) 13.99
Greenhouse	0.10	3.90	(+) 38.97
Soybean	0.09	3.89	(+) 41.30
Walnut	2.94	2.94	(*) 1.00
Grape	0.82	0.82	(*) 1.00
Apple	0.66	0.66	(*) 1.00
Almond	0.40	0.40	(*) 1.00
Peach	0.28	0.28	(*) 1.00
Nectarine	0.19	0.19	(*) 1.00
Apricot	0.15	0.15	(*) 1.00
Plum	0.08	0.08	(*) 1.00
Medicinal plants	0.07	0.49	(+) 7.17
Rose	0.06	0.06	(*) 1.00
Cherry	0.05	0.05	(*) 1.00
Olive	0.03	0.03	(*) 1.00
Pear	0.03	0.03	(*) 1.00
Saffron	0.03	0.06	(+) 2.32
Quince	0.02	0.02	(*) 1.00
Sour cherry	0.01	0.01	(*) 1.00

[a] The mark (-) means decrease, (+) means increase and (*) means unchanged. The table numbers are rounded.

approximately 95%, which indicates carrying out of the third constraint defined in the optimization problem. Similarly, the results showed that the ratio of gained benefit to the amount of water extracted from the wells for the current conditions and optimized conditions were 0.68 and 0.94, respectively, indicating the superiority of the optimized state over the current state.

As mentioned before, in the past years, only one similar research has been performed about optimization of cropping pattern using the optimization tool in Vensim PRO x32 software (Nozari and Mohseni, 2015). In that research, the objective functions are similar to the present study but the optimization constraints are different. On the other hands, supply percentage of water requirement for the crop pattern has not been considered in that study. Also, the optimal cropping pattern was determined based on the available information for a particular year in the past, while in the present study, cropping pattern has been determined based on climatic and hydrometric forecasting using time series modeling in future years. However, in both studies, different scenarios have been investigated to determine the optimal cropping

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pattern. Researchers in both studies believe that the optimization tool in Vensim PRO x32 software is a useful tool for cropping pattern optimization.

CONCLUSIONS

In the current study, in order to determine the optimum cropping pattern in Kermanshah Plain, west of Iran, a dynamic model covering the factors affecting the water resources status of the study area was developed in Vensim PRO x32 software. The results gained by dynamic model evaluation showed that the values related to the determination coefficient and percentage of computational error were 0.98 and ±2%, respectively, indicating the validity of the model for simulating the real system. Stochastic simulation of time series was used to predict the future climate parameters values. Examining the selected models for climatic parameters modeling on monthly scale showed that the prevailing model for precipitation, evaporation, potential evapotranspiration, and river discharge parameters was PARMA (1,0) model. In order to investigate the accuracy and efficiency of the time series model, two statistics of mean square error and Nash-Sutcliffe were used. Considering the values of these statistics in two situations, including training and testing of the model, showed that the accuracy and efficiency of selected models in modeling the desired parameters were acceptable. After assuring the performance of dynamic and time series models, the cropping pattern optimization using the optimization tool in Vensim PRO x32 software considering a multi objective mathematical programming approach by Powell method was performed for three different scenarios. These scenarios included possibility of changing the crop coefficients of all plants, possibility of changing the crop coefficients of all plants except for wheat, and finally, possibility of changing the crop coefficients of all plants except wheat and gardens. The objective functions included maximizing the benefit gained from crop cultivation and minimizing the amount of water extracted from the wells. The optimization constraints also included lack of change in total amount of the area covered by the cropping pattern in addition to fulfilling an aim of supplying crop water consumption used by crop pattern more than 80% in the optimized conditions. The obtained results demonstrated that the ratio of gained benefit to the amount of water extracted from wells in optimized conditions is always higher than the current conditions, which indicates the superiority of the optimized conditions over the current state. The mentioned ratios for the three scenarios were, respectively, 1.23, 0.89, and 0.94, which in all three scenarios are higher than the current value that is 0.68. Additionally, the results showed that in the scenario in which changes in the crop coefficients of all crops are possible, in order to optimize the cropping pattern, the area covered by wheat, barley, grain and forage maize, tomato, clover, and onion should be reduced in the current cropping pattern. Furthermore, the results of optimization indicated that the area covered by saffron, rose, greenhouse, medicinal plants, and olive under optimized conditions increased compared to the current conditions. The results of this study revealed that the use of system dynamics approach to simulate the real situation of the area, and subsequently, operating optimization process using optimization tool in Vensim PRO x32 software is a useful method for decision making and planning in agriculture sector to determine the optimum crop pattern. The following scenarios are suggested for future researches: consideration of other suitable plants for the cropping pattern, determination of optimum cropping pattern if it is permissible to increase or decrease the total area of agricultural lands, and determination of future climatic conditions by considering global climate change scenarios and its impact on optimum cropping pattern. Furthermore, model development is suggested to increase model ability to define more objectives for optimization in problems such as health of agro-ecosystems by optimizing the use of fertilizers and chemical pesticides.

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بهینه‌سازی الگوی کشت با استفاده از رویکرد سیستم دینامیک و برنامه‌ریزی ریاضی چندهدفه

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چکیده

در این مطالعه به منظور تعیین الگوی کشت بهینه دشت کرمانشاه در ایران، یک مدل دینامیکی در نرم‌افزار Vensim PRO x32 به منظور شبیه‌سازی شرایط واقعی منطقه تهیه شد. به منظور پیش‌بینی مقادیر پارامترهای اقلیمی در آینده، از روش شبیه‌سازی استوکاستیک سری‌های زمانی استفاده شد. پس از اطمینان از عملکرد مدل‌های دینامیکی و سری زمانی، عملیات بهینه‌سازی الگوی کشت به کمک ابزار بهینه‌سازِ موجود در نرم‌افزار Vensim PRO x32 با استفاده از رویکرد برنامه‌ریزی ریاضی چندهدفه به روش پاول در سه حالت مختلف انجام گرفت. توابع هدف شامل ماکزیمم شدن سود اقتصادی برای کشاورزان و مینیمم شدن آب استخراج‌شده از آبخوان بودند. نتایج نشان دادند که نسبت سود بدست آمده به مقدار آب استخراج شده از چاه‌ها در شرایط بهینه‌سازی شده همواره بیشتر از شرایط فعلی می‌باشد. مقدار این نسبت برای سه حالت بهینه‌سازی به ترتیب ۱/۲۳، ۰/۸۹ و ۰/۹۴ بود که در هر سه حالت بیشتر از مقدار آن برای شرایط فعلی می‌باشد (۰/۶۸). نتایج نشان داد در صورتِ امکانِ تغییر در ضرایب کشت تمام گیاهان، برای بهینه نمودن الگوی کشت فعلی بایستی مساحت تحت پوشش گندم، جو، ذرت دانه‌ای و علوفه‌ای، گوجه‌فرنگی، شبدر و پیاز در الگوی کشت فعلی کاهش داده شود. همچنین نتایج حاصل از بهینه‌سازی حاکی از افزایش مساحت تحت پوشش زعفران، گل محمدی، گلخانه، گیاهان دارویی و زیتون در شرایط بهینه‌شده نسبت به شرایط فعلی می‌باشد.