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Article

Applying a System Dynamics Approach for Modeling Groundwater Dynamics to Depletion under Different Economical and Climate Change Scenarios

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Abstract: In the recent decades, due to many different factors, including climate change effects towards be warming and lower precipitation, as well as some structural policies such as more intensive harvesting of groundwater and low price of irrigation water, the level of groundwater has decreased in most plains of Iran. The objective of this study is to model groundwater dynamics to depletion under different economic policies and climate change by using a system dynamics approach. For this purpose a dynamic hydro-economic model which simultaneously simulates the farmer's economic behavior, groundwater aquifer dynamics, studied area climatology factors and government economical policies related to groundwater, is developed using STELLA 10.0.6. The vulnerability of groundwater balance is forecasted under three scenarios of climate including the Dry, Nor and Wet and also, different scenarios of irrigation water and energy pricing policies. Results show that implementation of some economic policies on irrigation water and energy pricing can significantly affect on groundwater exploitation and its volume balance. By increasing of irrigation water price along with energy price, exploitation of groundwater will improve, in so far as in scenarios S15 and S16, studied area's aquifer groundwater balance is positive at the end of planning horizon, even in Dry condition of precipitation. Also, results indicate that climate change can affect groundwater recharge. It can generally be expected that increases in precipitation would produce greater aquifer recharge rates.

Keywords: groundwater; system dynamics; modeling; climate change; economic policy

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1. Introduction

Globally, at least two billion people depend upon groundwater as the principal source of their drinking water [1,2]. Also, over the last fifty years, groundwater development has played a fundamental role in agricultural production in many parts of the developing world [3]. Dependence upon groundwater is specially important in areas such as Northern China, Eastern Europe, Northern India, the US Great Plains and the largest parts of the middle east countries [4]. In the recent decades, due to many different factors, including climate change effects towards be warming and lower precipitation, as well as some structural policies such as more intensive harvesting of groundwater for agriculture development, low price of irrigation water, inefficient water use, the level of groundwater has decreased in most areas of Iran [5]. Recent forecasts suggest that the combined effects of population growth, global warming and land use change will, in the near future, lead to even greater reliance on groundwater for public water supply [6,7]. Some researches indicate that, in scenario of climate change trend toward further warming and low precipitation, economic policy instruments for groundwater demand management, including input and output pricing policies related to the agricultural sector, as the biggest consumer of water resources in the world, can play an important role in ensuring a better control of groundwater resource exploitation [8]. Due to the common pool nature of aquifers, economists have long claimed that when groundwater is extracted under competition, a series of externalities prevent the efficient exploitation of the resource [9]. Given the spatial-dynamic nature of groundwater flow, the extent of all these externalities depends upon quantity, location and time of extraction and on the type of strategic behavior under competition [10]. In the presence of a competitive and unregulated extraction regime, the temporal and spatial profile of external effects results in inefficient pricing and misallocation of the resource [9]. So, it can be concluded that adequate use of some economical instruments such as energy and irrigation water pricing under competition structure, can significantly reduce groundwater exploitation toward sustainable management of aquifer groundwater in some countries like Iran, in which prices of production factors, especially water, have not been defined in a competitive and real condition. Changes in groundwater vulnerability patterns are the result of human-environment-climate interactions across a range of spatial and temporal scales [11]. However, efficient and sustainable management of groundwater resources is increasingly becoming a policy objective. In this context, the complexity of water resources management requires an integrated biophysical and economic modeling in the framework of dynamic hydro-economic models [12]. Understanding the impact of climate change and government programs about agricultural production on groundwater vulnerability, under the different scenarios, is essential for ensuring the sustainability of future groundwater resources.

Groundwater resources, which represent about one quarter of freshwater on earth [13], are the only main source of irrigation and drinking water in somearid and semi-arid regions such as the Hamedan-Bahar Plain, situated in the western Iran [5]. The aim of this study is to analyse and forecast the vulnerability of groundwater level and agriculture sector water consumption in Hamedan-Bahar plain, under different climate change and agricultural economic policies using the system dynamics (SD) approach. System dynamics is the theory of system structures and a set of tools for representing complex systems and analyzing their dynamic behavior [14]. The SD approach is a policy-based methodology that evaluates the effect of policy changes on a system [15]. The most important feature of this approach is to elucidate the endogenous structure of the system under study, to see how different elements of the system actually relate to one another, and to experiment with changing relations within the considered system when different decisions are included [16]. The SD approach is an appropriate technique for simulating complex problems in integrated water resources [17]. In the Hamedan-Bahar plain, lack of adequate surface water, rainfall and duration mismatch causes excessive pressure on groundwater resources, which supply more than 80 percent of agricultural water and 50% of drinking water [18]. As a result, in the past 30 years, the water table in Hamedan-Bahar plain lowered. In this plain, government subsidies for agricultural activities and the lack of payments by farmers for groundwater usage has encouraged farmers to an inefficient increase of the number of wells and irrigated farms, with no consideration for groundwater resource conservation. Consequently, the level of groundwater has decreased continuously in recent decades, threatening the life of groundwater aquifer in this area [19]. Research on the groundwater balance of the study area indicates that the adjustment of agricultural policies will be effective in ensuring optimal groundwater exploitation in the agriculture sector, given the vast amount of aquifer water that is consumed in this area [20–22]. The objective of this study is to model groundwater dynamics to depletion under different economic policies and climate change by using system dynamics approach. For this purpose a dynamic hydro-economic model which simultaneously, simulates farmer's economic behavior, groundwater aquifer dynamics, studied area climatology factors and government economical policies related to groundwater, is developed using STELLA 10.0.6 (STELLA is the leading systems modeling tool for education and research, used at all educational levels to stimulate learning for subjects such as economics, physics, literature, calculus, chemistry, and public policy. STELLA models allow you to communicate how a system works—what goes into the system, how those inputs impact the system, and what are the outcomes).

2. Materials and Methods

Hamedan-Bahar aquifer is located in Hamedan province, Iran, and lies between longitudes 48°17' E and 48°33' E and latitudes 34°49' N and 35°02' N. The total area of Hamedan-Bahar aquifer is 480 km^2 and the aquifer is unconfined (Figure 1). The study area has a cold semi-arid climate with an average annual precipitation of 325 mm and mean annual temperature of 11 °C [23]. The dynamic relations between variables in the STELLA model, is illustrated in Figure 2, as a dynamic flow diagram. In this diagram, groundwater volume as a stock variable depends on two components of inflow and outflow rate variables which effect groundwater dynamics. Groundwater volume fluctuations depend on precipitation, sewage water and surface water percolation, artificial recharge programs, and subsurface inflows which enter into the aquifer balance system, whilst other variables include crops water use, moisture remained in the soil, evaporation, subsurface outflows and groundwater extraction outflow from the aquifer. In this model, extraction of groundwater for agricultural activities is determined by farmer's economical behavior and indirectly depend on farmers net income in the study area. Clearly, farmer's economic behavior is sensitive to some related economic policy instruments including inputs and output pricing policies such as energy and irrigation water pricing. That is, with the implementation of economic policy instruments in the agriculture sector, farmers will respond to policies by changing their cropping pattern and production technologies. Logically, by agriculture sector adaptation to economic policies, the exploitation of aquifer groundwater and its volume fluctuations will be also compatible, as shown in the dynamic flow diagram. The main mathematical equations and relations between model variables are briefly described in Equations (1) to (19). Groundwater volume balance is described in Equations (1) to (7).

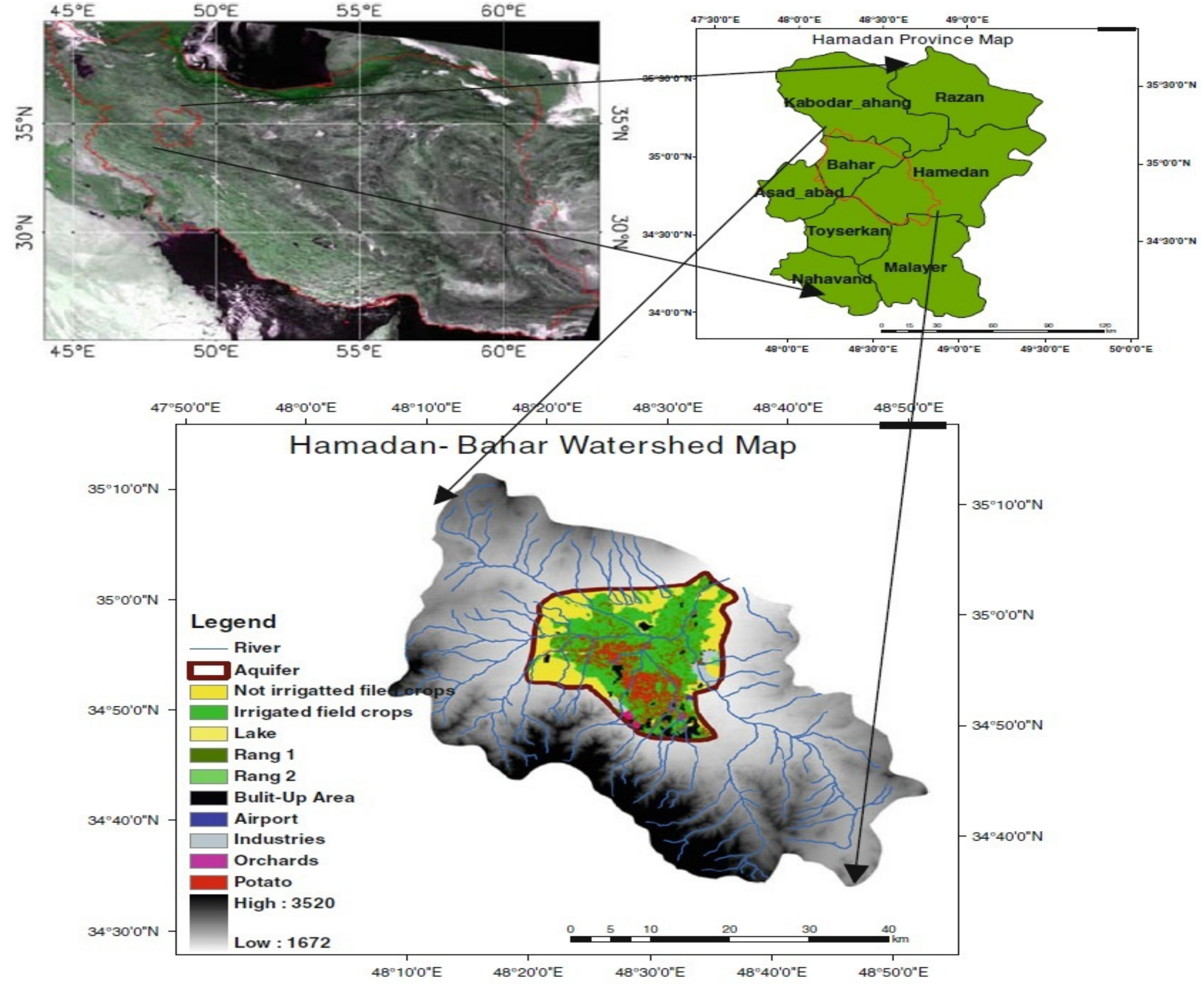

Figure 1. Location of study area of Hamedan-Bahar Plain, Hamedan Province, Iran [23].

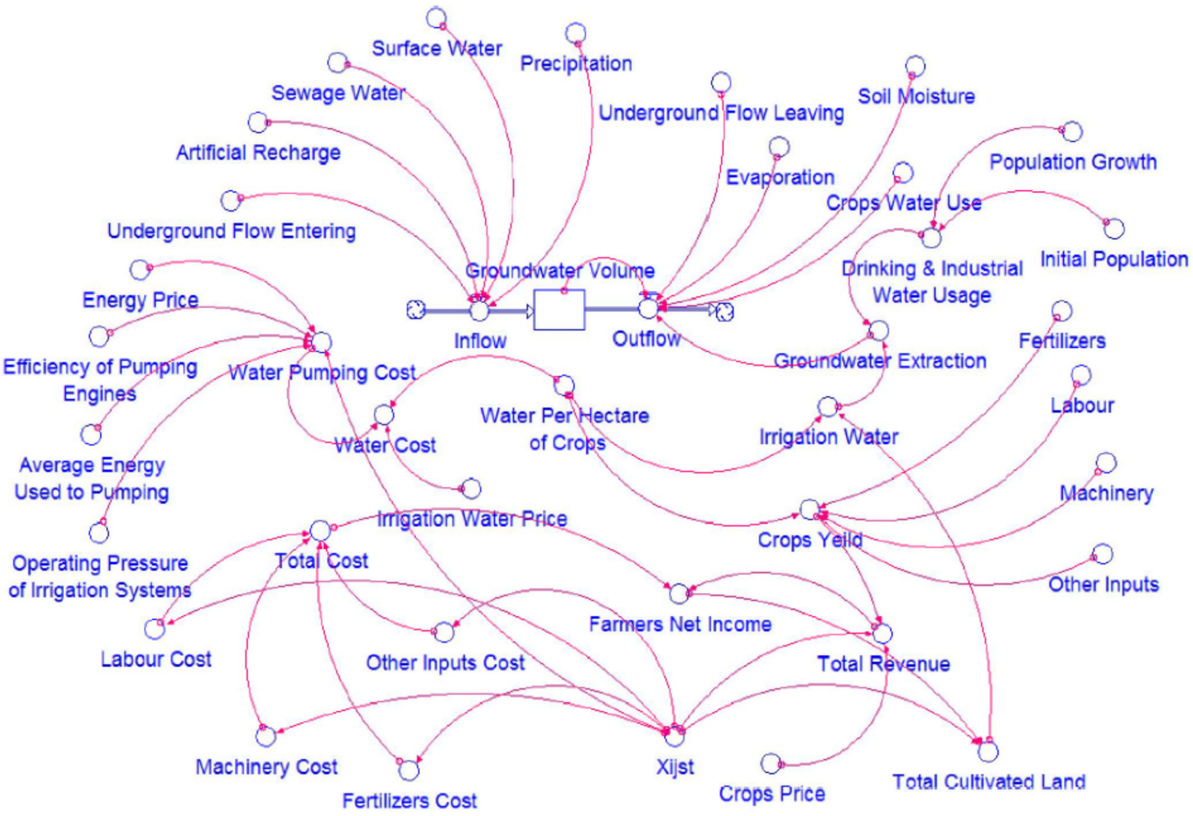

Figure 2. STELLA dynamic flow diagram of studied groundwater dynamics.

For the hydrologic system to be in balance, water inflows to aquifer must equal the water outflows [5].

$$\mp \Delta V_t = (\Pr e_t + Agw_t + Sw_t + Sew_t + AR_t + Q_t^{in}) - (Q_t^{EX} + Pltw_t + Q_t^{out} + Eva_t + Mo_t) \quad (1)$$

$$Sw_t = Sw(\Pr e_t) \quad (2)$$

$$Pltw_t = w(\Pr e_t) \quad (3)$$

$$Eva_t = e(\Pr e_t) \quad (4)$$

$$Mo_t = m(\Pr e_t) \quad (5)$$

$$Q_t^{in} = q(\Pr e_t) \quad (6)$$

$$\Pr e_t = \{D, N, W\} \quad (7)$$

where: ΔV_t, is fluctuation of groundwater volume (m^3); $\Pr e_t$, precipitation (m^3) in three different scenarios of N (Normal), W (Wet) and D (Dry) as representative of climate conditions; Agw_t, exploitation of groundwater for agriculture (m^3); Sw_t, surface water flow (m^3); Sew_t, sewage of municipal and industrial water (m^3); AR_t, artificial recharge of aquifer (m^3); Q_t^{in}, overall underground flow entering to aquifer(m^3); Q_t^{EX}, extraction of aquifer for agricultural, municipal and industrial usage (m^3);$Pltw_t$, net water used by crops (m^3); Q_t^{out},overall underground flows leaving the aquifer; Eva_t, evaporation (m^3); Mo_t, moisture which remains in empty space of soil of study area (m^3). In this model, variables of net water used by crops, evaporation and soil moisture are determined respectively as Equations (8) to (9) as follows:

$$Pltw_t = \gamma_1 Agw_t + \lambda_1 \Pr e_t + \alpha_1 Sw_t + \beta_1 Sew_t + \mu_1 AR_t \quad (8)$$

$$Eva_t = \gamma_2 Agw_t + \lambda_2 \Pr e_t + \alpha_2 Sw_t + \beta_2 Sew_t + \mu_2 AR_t \tag{9}$$

$$Mo_t = \gamma_3 Agw_t + \lambda_3 \Pr e_t + \alpha_3 Sw_t + \beta_3 Sew_t + \mu_3 AR_t \tag{10}$$

where: parameters γ is net portion of agriculture irrigation water inflows to groundwater balance zone; λ, net portion of precipitation inflows to groundwater balance zone; α, net fraction of surface water inflows to groundwater balance zone; β, net portion of municipal sewage water inflows to groundwater balance zone; and μ is net portion of artificial recharge water inflows to groundwater balance zone. In the dynamic flow diagram (Figure 2), the variable of NPVR (Net Present Value of Returns) is the total net present value of returns of agriculture sector in the planning horizon (t), which is considered to be Equation (11), and, *NI* is farmers net income which is calculated as Equation (12).

$$NPVR = \sum_{t=1}^{n} NI_t (1+r)^{-t} \tag{11}$$

$$NI_t = \sum_i \sum_j \sum_s X_{ijst} \left[P_{it} Y_{ijst}(Pltw_t, Land_t, Labor_t, Fer_t, Mach_t ...) - C_{ijst}(WatC_t, LabC_t, FerC_t, MachC_t, OC_t) \right] \tag{12}$$

$$C_{ijst} = WatC_{ijst} + LabC_{ijst} + FerC_{ijst} + MachC_{ijst} + OC_{ijst} \tag{13}$$

$$WatC_{ijst} = (PC_{ijst} + PW) * WP_{ijst} \tag{14}$$

where NI_t is net income of agriculture sector; i is the crop index, $i = 1$ to n; j, irrigation system index, $j = 1, 2$; s, index of zones in the study area, $s = 1, \ldots, 4$; t, index of time in the planning horizon as cropping year, $t = 1, \ldots, 5$; X_{ijst}, area allocated to crop i produced by j system of irrigation in zone s at year t (ha); P_{it}, price of crop i in year t; Y_{ijst}, yield of crop i produced by irrigation system j in zone s at year t (per ha); C_{ijst}, production cost of crop i produced by irrigation system j in zone s at year t (per ha); $WatC_{ijst}$, groundwater consumption cost of crop i produced by irrigation system j in zone s at year t (per ha); WP_{ijs}, extracted groundwater per hectare of crop i produced by using irrigation system j in the zone s; PW_t is price of groundwater at time t and r represents the social discounted rate. In this research, groundwater pumping cost (*PC*) is calculated on the basis of Terrel study as Equation (15) [5], in which, *EP* is the price of energy; *EFF*, efficiency of groundwater pumping engines; *EF*, average energy used to pumping and distributing groundwater; L_t, height of groundwater pumping; *PSI*, operating pressure of irrigation systems.

$$PC_{ijst} = EF(L_t + 2.31 * PSI)EP / EFF \tag{15}$$

The whole extraction of aquifer groundwater includes extraction for agricultural activities irrigation (Agw_t), and extraction for municipal and industrial usage (MIw_t). Pumping and extraction of groundwater for irrigation is a function of crops water use per hectare (*WP*), and cultivated area of all crops (X_{ijst}) as an endogenous variable, which is determined Equation (17). Also, extraction of groundwater for drinking and municipal purposes depends on population growth as Equation (15), in which, (*IMI*), is initial groundwater consumption for drinking consumptions and (*pg*) is annual population growth rate.

$$Q^{EX}{}_t = Agw_t + MIw_t \tag{16}$$

$$Agw_t = \sum_i \sum_j \sum_s X_{ijst} . WP_{ijst} \tag{17}$$

$$MIw_t = IMI\,(1 + pg)^t \tag{18}$$

When groundwater volume changes due to individual variables of the aquifer balance equation (such as precipitation or exploitation) the water table depth also changes according to the following Equation [5].

$$\Delta S_t = S_t - S_{t-1} = \Delta V . \frac{1}{A.q} \tag{19}$$

in which, S_t is the water table depth (height of water pumping) in year *t*; A is the area of aquifer (m^2), and *q* is the specific yield of the aquifer [5,8].

3. Results

In this study, firstly, different scenarios containing future climate changes on precipitation and some economic policy instruments related to groundwater exploitation in the agriculture sector, defined on the basis of I.R.IRAN's government programs are combined, as shown in Table 1. These scenarios are composed of three effective economic policy instruments, including water price, energy price and crops prices in a reasonable range according to government programs at the planning horizon. In order to consider the effects of climate changes as precipitation fluctuations on groundwater balance and its vulnerability, three climate scenarios including Dry, Normal and Wet precipitation, also are added to dynamic model [24]. In this research, the Dry precipitation scenario varies from 170 to 290 mm, the Normal from 291 to 350 mm and the Wet from 351 to 500 mm, on the basis of seasonal distribution of long term precipitation observed at meteorology stations in the study area.

Table 1. Different integrated economic policy scenarios in agriculture sector.

Scenario	Water Price (Dollar per m^3)	Energy Price (EP)	Crops Prices (P)	Future Precipitation		
S0	Baseline	Baseline	Baseline	D	N	W
S1	0	100% annual growth	20% increase	D	N	W
S2	0	150% annual growth	20% increase	D	N	W
S3	0	100% annual growth	10% increase	D	N	W
S4	0	150% annual growth	10% increase	D	N	W
S5	0.07	Baseline	10% increase	D	N	W
S6	0.07	Baseline	20% increase	D	N	W
S7	0.07	100% annual growth	20% increase	D	N	W
S8	0.07	150% annual growth	20% increase	D	N	W
S9	0.07	100% annual growth	10% increase	D	N	W
S10	0.07	150% annual growth	10% increase	D	N	W
S11	0.1	Baseline	10% increase	D	N	W
S12	0.1	Baseline	20% increase	D	N	W
S13	0.1	100% annual growth	20% increase	D	N	W
S14	0.1	150% annual growth	20% increase	D	N	W
S15	0.1	100% annual growth	10% increase	D	N	W
S16	0.1	150% annual growth	10% increase	D	N	W

The groundwater volume fluctuations and the changes of water table depth, under Dry climate condition for the planning horizon of 5 years, are described in Table 2. In the baseline scenario (S0), in which economic variables reflect the current situation, results show that if the production of producing agricultural and industrial products and also municipal consumption of groundwater in the study area continues, aquifer groundwater volume will be decreased by more than 232 million m^3 and the height of water table will reduce with 6.62 m (Table 2). In this scenario, the study area is predicted to be drier at the end of planning horizon. By increasing energy price as a complementary input of irrigation water, in scenarios S2, S3 and S4, the total exploitation of groundwater decreases and the changes of water table depth improve respectively to −6.49, −6.52 and−4.75 m at the end of planning horizon (Figure 3). It is reasonable that by increasing of energy price, the extraction cost of irrigation water grows and this fact can reduce groundwater consumption for irrigation purposes in the study area. Increasing of irrigation water price as another alternative of economic policy instrument under scenarios S5, in which crops prices will increase about 10%, due to farmers behavior reaction to increasing of irrigation water price, the groundwater balance at the end of planning horizon will be −206 million m^3. But, under scenario S6, by 20% increase of crops prices, irrigation water pricing policy at this level (PW =0.07 $), not only do not reduce groundwater extraction but also increases its depletion. Results show that by increasing of irrigation water price along with agriculture energy price,exploitation of groundwater will improve, in so far as in scenario S16 (PW = 0.1, energy price increasing = 150% and crops price increasing = 10%). Studied area's aquifer groundwater balance is positive at the end of planning horizon, even in Dry condition of precipitation.

In the scenario S16, including an increase of irrigation water price to 0.1 dollar per m^3, significant increase of energy price (150% to base scenario), and 10% increase of crops prices (because of production factors price increase), the volume of groundwater in the studied aquifer is 62 million m^3 and the water table depth will decrease with approximately 1.76 m. As it is clear from Table 2, the water table depth, is positive only in scenarios S10, S15 and S16.

Table 2. Groundwater volume fluctuations under different economic scenarios in the Dry climate condition on the planning horizon.

Scenario	Groundwater Balance in the Planning Horizon ($+\Delta\bar{V}_t$) (million m^3)	$\%+\Delta\bar{V}_t$ To Baseline Scenario	Changes of Height of the Water Table (ΔS_t) (m)	$\%\Delta S_t$ To Baseline Scenario
S0	−232	-	−6.62	-
S1	−239	−3.06	−6.82	−3.02
S2	−228	1.94	−6.49	1.96
S3	−228	1.59	−6.52	1.15
S4	−166	28.1	−4.75	28.2
S5	−206	11.34	−5.87	11.32
S6	−242	−4.42	−6.91	−4.38
S7	−171	26.2	−4.88	26.28
S8	−147	36.7	−4.19	36.70
S9	−10.3	95.53	−0.29	95.61
S10	56.9	124.4	1.62	124.47
S11	−155	33.1	−4.42	33.23
S12	−232	−0.16	−6.63	−0.15
S13	−153	34.16	−4.36	34.13
S14	−119	48.4	−3.41	48.48
S15	42.7	118.3	1.21	118.2
S16	62	126.6	1.76	126.5

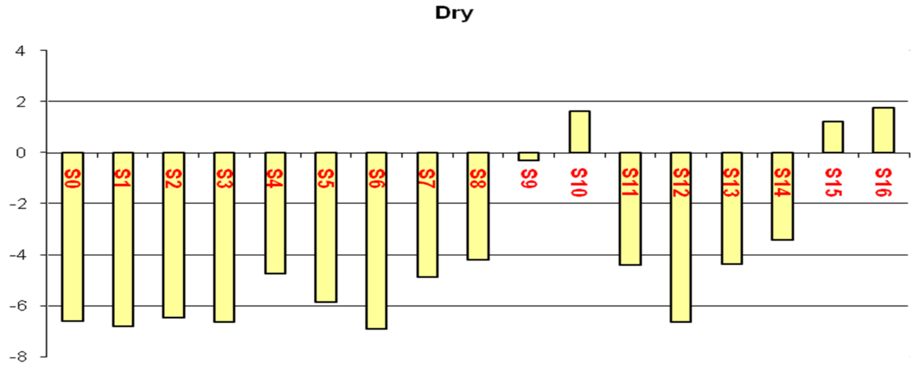

Figure 3. Height of water table under different economic scenarios in Dry climate condition on the planning horizon.

Results show that, under the normal condition of future precipitation in the study area, the volume of aquifer groundwater will improve in all scenarios in comparison of the Dry scenario. It is clear that, under the normal climate conditions, also, implementation of some economic policies such as efficient pricing of irrigation water, energy and other factors, can significantly affect the groundwater exploitation and its volume balance. As declared in Table 3, the performance of these policies on the base of all scenarios in normal future climate, will improve groundwater volume balance and water table height exception of scenarios S1, S6 and S12, in which economic instruments are not sufficiently effective and strong.In the Normal condition of precipitation, by increasing of energy price in scenarios S2, S3 and S4, the total exploitation of groundwater decreases and the balance of aquifer groundwater will be respectively −46.9, −47.7 and 14 million m^3. As shown in Figure 4, in the scenario S6 where the irrigation water price is 0.7 $, the energy price has increased 150% and crops price has grown 20% to base scenario, the balance of aquifer groundwater will get worse as at end of the planning horizon, by reduction of 10.3 million m^3 has decreased to −61.7 million m^3. Under scenarios of S7 to S10 in which both irrigation water and energy price are simultaneously increased, the water table depth has improved (Figure 4), and the groundwater balance in scenario S10 has reached to 238 million m^3. The explanation for this behavior is that in scenario S6, the effect of irrigation water and energy price increasing is neutralized by growing crops price. In the Wet scenario of climate condition, the groundwater balance is improved in all scenarios of irrigation water and energy price increasing policies (Table 4). In this case, even on baseline scenario (S0), without consideration of any economic policy, the groundwater volume balance, at end of the planning horizon will be positive and nearly to 223 million m^3. By increasing of energy price in scenarios S2, S3 and S4, the total exploitation of groundwater decreases and the balance of aquifer groundwater will be respectively 227, 226 and 288 million m^3. As shown in Figure 5, in the scenario S6 the balance of Hamedan-Bahar plain groundwater will get worse as at end of the planning horizon by reduction of 11 million m^3 has decreased to 212 million m^3. Under scenarios of S7 to S10 in which both irrigation water and energy price are simultaneously increased, the water table depth has improved (Figure 4), and the groundwater balance in scenario S10 has reached to 512 million m^3.

Results show that under the Wet conditions of future climate in Hamedan-Bahar plain all scenarios will lead to positive balance of aquifer groundwater, but by implementation of economic policy scenarios, this groundwater balance generally will further improve (Figure 5).

Table 3. Groundwater volume fluctuations under different economic scenarios in Normal climate conditions on the planning horizon

Scenario	Groundwater Balance in the Planning Horizon $(+\Delta\bar{V}_t)$ (million m^3)	$\%+\Delta\bar{V}_t$ To Baseline Scenario	Changes of Height of the Water Table (ΔS_t) (m)	$\%\Delta S_t$ To Baseline Scenario
S0	−51.4	-	−1.46	-
S1	−58.6	−13.8	−1.67	−14.38
S2	−46.9	8.78	−1.33	8.90
S3	−47.7	7.19	−1.36	6.84
S4	14	127.3	0.4	1273
S5	−25	51.2	−0.71	51.36
S6	−61.7	−19.9	−1.76	−20.54
S7	9.5	118.53	0.27	118.4
S8	33.9	165.8	0.96	165.7
S9	170	431.5	4.8	428.7
S10	238	562.3	6.78	564.3
S11	25.6	149.8	0.73	150
S12	−51.8	−0.73	−1.47	−0.68
S13	27.9	154.3	0.79	154.1
S14	61	218.6	1.74	219.1
S15	22.3	143.4	6.37	536.3
S16	243	−572.1	6.92	573.9

Table 4. Groundwater volume fluctuations under different economic scenarios in Wet climate condition on the planning horizon

Scenario	Groundwater Balance in the Planning Horizon $(+\Delta\bar{V}_t)$ (million m^3)	$\%+\Delta\bar{V}_t$ To Baseline Scenario	Changes of Height of the Water Table (ΔS_t) (m)	$\%\Delta S_t$ To Baseline Scenario
S0	223	-	6.35	-
S1	216	−3.19	6.15	−3.14
S2	227	2.02	6.48	2.04
S3	226	1.65	6.46	1.73
S4	288	29.37	8.22	29.44
S5	249	11.82	7.1	11.81
S6	212	−4.6	6.06	−4.56
S7	284	27.3	8.09	27.4
S8	308	38.2	8.7	37
S9	445	99.5	12.6	98.42
S10	512	129.7	14.6	129.9
S11	300	34.5	8.55	34.6
S12	222	−0.16	6.34	−0.15
S13	275	23.58	8.62	35.74
S14	335	50.4	9.56	50.55
S15	498	123.3	14.2	123.6
S16	517	132	14.74	132.1

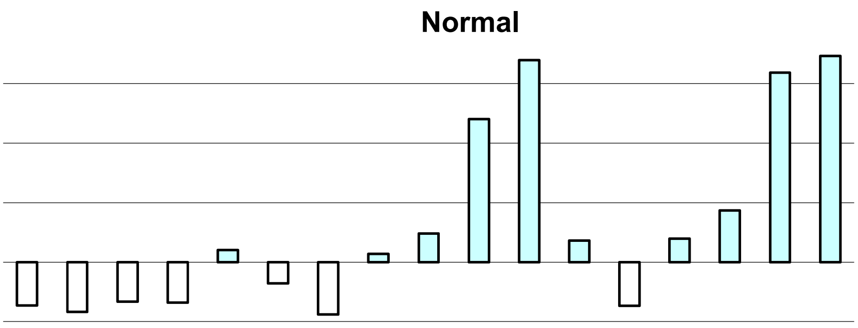

Figure 4. Height of water table under different economic scenarios in Normal climate condition on the planning horizon

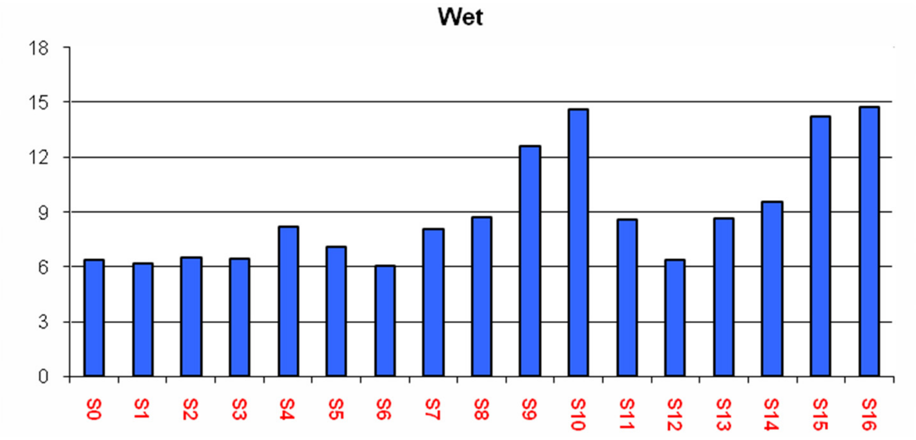

Figure 5. Height of water table under different economic scenarios in Wet climate conditions on the planning horizon.

4. Discussion

The system dynamics approach as a hydro-economic model has been proposed to analyse and forecast groundwater volume fluctuations under different scenarios of economical polices and climate changes in Hamedan-Bahar plain. In this study, future changes in groundwater were modeled as the effects of a combination of some economic instruments including irrigation water and energy pricing and climate changes. These factors were combined in a linear model to forecast changes in groundwater vulnerability. However, this first limitation of proposed model should be taken into account in interpreting and using the results for policy making.

The results of the simulation study demonstrate that the system dynamics approach applied to forecasting of groundwater volume fluctuations can be effective in explaining the relationship between model's economical and hydrological variables. In the model, groundwater volume change is determined by farmers economical behavior, municipal extraction of groundwater for drinking and industrial activities and also by climate conditions. However, this comprehensive dynamic hydro-economic model can not only predict and provide the all dynamic relations between studied system variables, but is also able to estimate groundwater reactions to some climate changes and related economic policies including agricultural input-output pricing policies on the framework of borders set for the studied system. Considering this point would make the modeling of all aspects of groundwater dynamics more realistic yet more complex in the studied area; that is clearly beyond the scope of this paper. Consistent with previous work, we find that there are potentialities for some efficacy of irrigation water and energy pricing instruments in the Hamadan-Bahar plain, which are very differentiated depending on the price level [5,8]. Another important limitation of this model that should be taken into policy making is forecasting of precipitation as representative of climate change of studied area. Because of this factor has very important effects on groundwater balance and also is difficult to exactly prediction.

Clearly, low price or no payment for irrigation water intensifies groundwater exploitation, as low water prices have been widely blamed for the poor efficiency in irrigation systems [25]. The results of integrated groundwater management scenarios, as part of the effort for improving groundwater conservation, indicated that application of irrigation water pricing policy toward its competitive market price has a significant effect on groundwater exploitation in the Hamedan-Bahar plain. According to previous studies it can be found that increasing the price of irrigation water with other integrated policies creates incentives for improving the its allocative efficiency, and for better management [5,8,25].Results showed that by increasing of irrigation water price under scenarios of S5 to S16, groundwater extraction in the study area will be considerably reduced and the overexploitation of groundwater will be adjusted. So, it can be concluded in the some situations, implementation of economic policy instruments is efficient to control groundwater extraction, as indicated in previous works [9,12,25]. Also, research results showed that increasing of energy price as a complementary inputs of irrigation water [5], can reduce exploitation of groundwater.

5. Conclusion

A dynamic hydro-economic model has been developed to investigate the vulnerability of Hamedan-Bahar aquifer groundwater to depletion under various economic policies and future climate changes scenarios.Some important insights can be drawn from the results above presented. Firstly, groundwater exploitation is affected by many factors including economical, hydrological and climate factors. Groundwater consumption management is complex, especially under conditions where climate and economic changes are difficult to project and predict.The modeling results have shown that, under all future scenarios analysed, implementation of integrated groundwater management policies including irrigation water pricing and energy pricing, groundwater exploitation and its balance significantly will be improved. It can be concluded that the use of some economical instruments such as energy and irrigation water pricing under competition structure, can significantly reduce groundwater exploitation toward sustainable management of aquifer groundwater. The results indicated that climate change can affect groundwater recharge. Also, Under the Normal and Wet climate scenarios, some variables which enter into the aquifer balance system will be increased and the groundwater balance will be improved. A number of studies have indicated that climate change can affect groundwater recharge [11,26–28] and increases in precipitation would generally be expected to produce greater aquifer recharge rates [2,29]. So, alongside using of economical policy instruments, planning and applying of some methods to control climate factors such as precipitation, meaningfully are a part of each comprehensive program to management of groundwater balance vulnerability.

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