Groundwater level modelling using system dynamics approach to investigate the sinkhole events (case study: Abarkuh County Watershed, Iran)

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Abstract: In the past few decades, withdrawal of groundwater and depletion of aquifers has increased; the aquifers have a negative balance in many plains and consequently, an endangering phenomenon called sinkholes have turned up. This phenomenon has created a concern for the people who lives in Abarkuh county watershed as well. This study attempts to investigate the factors most likely to cause a sinkhole event and evaluation of management strategies, by applying system dynamics approach. The results showed the verification of the model in simulating the groundwater level of the watershed. Moreover, the effects of crop pattern factor in the declining trend of groundwater level and increasing trend of depth of sinkhole event have been detected. In contrast, reducing the irrigation water demand, the withdrawal more than the requirement, and drinking water consumption, as management scenarios, demonstrated the most influence in order to prevent of sinkhole occurrence in the future, respectively.

Keywords: aquifer; sinkhole; system dynamics approach; Vensim; Abarkuh County Watershed.

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1 Introduction

In the recent years, sinkhole event is known as a serious and endangering phenomenon in most parts of the world. Human activities are an undeniable fact, as an effective impact, in order to intensify the occurrence of this phenomenon (Rahmanian, 1986). Population growth and agricultural development has led to increasing demand and consumption of water in drinking and agricultural sectors. Therefore, in areas that are facing with a shortage of surface water or the lack of it, withdrawal from the aquifers has increased.

Then these extreme withdrawals have led to the generation of a negative balance in aquifers and a drastic drawdown in the groundwater levels (Lashkari Pour et al., 2004). Consequently, some natural processes occur on the ground such as wellbore wall destruction, land subsidence and sinkhole, as well as movement of saline water from coastal and desert areas toward aquifers (Rahmanian, 1986; Metcalfe and Hall, 1984). Sinkholes may vary in size from 1 to 600 m both in diameter and depth, and vary in form from the soil-lined bowls to bedrock-edged chasms. Sinkholes may be formed gradually or suddenly, and are found worldwide (Kohl, 2001; Huske, 2006).

For the first time, Aley et al. (1972) noted in some examples of sinkholes which occurred in the USA. He exhibited that the over-pumping and extreme withdrawals of water fluctuate the water table which create a sinkhole. Several studies have also been done in the field of sinkhole events by Brink (1984), Metcalfe and Hall (1984) and Newton (1987). They presented that the drawdown of groundwater levels drastically are the most effective factor in occurring of this occurrence. In Iran, the land subsidence phenomenon has been reported for the first time in agricultural wells in Rafsanjan County due to extreme extraction from the aquifers in 1967 (Hoseioni Milani, 1994). The some done researches in Iran have also presented that dropping water table is the main factor in forming of sinkholes and land subsidence events (Rahmanian, 1986; Lashkari Pour et al,. 2004). In another study, Bagheri Harooni et al. (2012) investigated crisis of Qanats in Abarkuh Watershed using system dynamics (SD) approach. The results of modelling showed that the main factor in drying of Qanat is the extreme extraction of water wells. Moreover, the continuation of the current withdrawals will dry the remaining Qanats in the future years.

Groundwater management, particularly in a rural watershed like Abarkuh which is the main water sources, is an excellent example of a system with dynamic complexity (Giordano et al., 2012). Integrated management of the basin thanks to the SD approach has been studied in many basins and performed well, and proved to be an excellent tool to assess and manage water resources in the basin (Madani and Mariño, 2009). In general, SD is a methodology and mathematical modelling technique for farming, understanding, and discussing complex issues and problems. In the SD methodology, a problem or a system is first represented as a casual loop diagram. Casual loops diagrams aid in visualising a system's structure and behaviour, and analysing the system qualitatively. To perform a more detailed quantitative analysis, a casual loop diagram is transformed to a stock and flow diagram. A Stock and flow model helps in studying and analysing the system in a quantitative way; such models are usually built and simulated using computer software (Sterman, 2000). In the recent two decades, sinkhole phenomenon has frequently occurred in Abarkuh County Watershed of Iran. The aim of this study is to:

1 modelling the groundwater levels in study area using the SD approach

2 investigate the management scenarios in order to prevent sinkhole occurrence in the future and retrieval of the water table; which relatively few efforts have been done in this field dynamically and systemically.

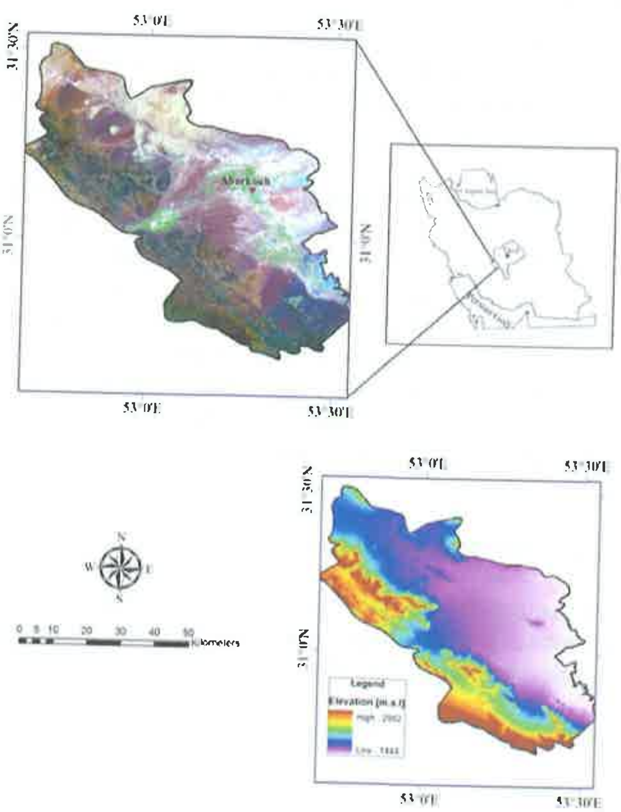
Generally, SD approach application for solving such problems has not been applied yet in Iran.

2 Materials and methods

2.1 Study area

The study area is the Abarkuh County Watershed, which is located in the west part of Yazd Province (approximately between 52°40' and 53°30' longitude; 30°41' and 31°30' latitude) in Iran and, having 3,760 km^2 and the average elevation of 1,776 m above sea level (Figure 1). The mean annual precipitation from 1996 to 2006 of the study area is about 72 mm, the annual evaporation is about 3,171 mm and the mean annual temperature is 16.7°C. At the 2006 census, the county's population is 43,595 with an average growth rate 1.1%. In general, the water resources of this watershed are limited to groundwater, and the cultivation area in this region is also 15,444.4 hectare. On average 159 MCM groundwater is annually extracted which due to uncontrolled withdrawals, the average decline rate of groundwater level is 58 cm per year. In the study area, the depth of wells is between 30 and 200 metres (depending on geographical location). From the view point Hydrogeology, the aquifer encompasses the area of about 1,279 km^2, the Storage coefficient is about 0.58 and the transmission coefficient vary from 60 to 600 m^2/day. Also, aquifer is not uniform in terms of hydrogeological and each has especial characteristics. It should be noted that these hydrogeological properties have been calculated using 3 out of 11 exploratory wells in the study area (Yazd Regional Water Authority, 1994; Abangah Consulting Engineering Company, 2006).

Figure 1 The study area (Abarkuh County Watershed) (see online version for colours)



2.2 Problem definition and conceptual model

In July 2009, a sinkhole occurred suddenly with a diameter of 50 m, a depth of 16 m, and an average slope of about 75 degrees toward the hole in the study area. Similar occurrences in this plain have been formed in 1993. Since 1993 till now has been reported more than 30 sinkhole events which their depth and diameter are between 2–16 and 3–50 metres (Geological Survey of Iran, 2009). It should be mentioned that sinkholes with a depth lower than 2 m is not considered in this study. Figure 2 displays the global position of occurred sinkholes in the watershed. Table 1 also shows the characteristics of these sinkholes.

Figure 2 Overall positioning of occurred sinkholes in watershed (see online version for colours)

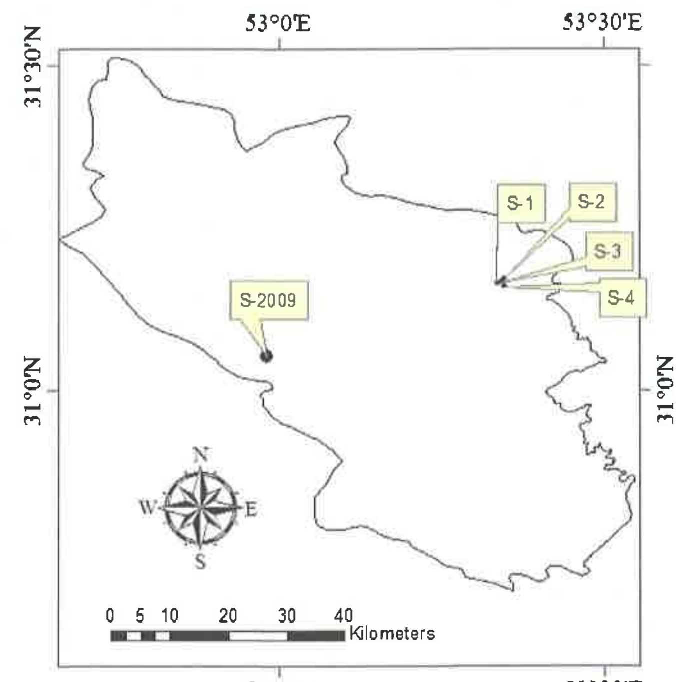


Table 1 Characteristics of occurred sinkholes in watershed

Sinkhole ID	*Occurrence year*	*Depth (m)*	*Radius (m)*	*Geographical position*
S-1	1993	10	20	53°17' E, 31°9' N
S-2	1993	8	3	53°14' E, 31°10' N
S-3	1993	7	3	53°16' E, 31°11' N
S-4	1993	12	5	53°15' E, 31°12' N
S-2009	2009	16	25	52°54' E, 31°1' N

In the case of Abarkuh County Watershed, various factors, which are effective on the occurrence of sinkholes, divided into two categories: human and environmental factors. Human being investigation on the nature through population growth, agricultural development and consequent water demand increasing is one of the human factors. As mentioned in Section 1, population growth, increase in agricultural lands and change in cropping pattern with the more water requirement is causing an increasing trend in demand. Consequently, in order to satisfy the demands the supply increase, after that the water extraction increases and finally, the groundwater levels fall and the sinkhole event occur in the study region. On the other hand, this drawdown of level decreases the aquifer discharge that lead to decreasing of supply and consequently, the water supply for drinking and agriculture is faced with shortage (Rahmanian, 1986; Lashkari Pour et al., 2004). As a result, the water shortage is caused the decreasing of cultivation area and water demand. These factors, in this research, are studied as endogenous factors.

Environmental factors like climatic variables (such as precipitation, temperature, evapotranspiration) and aquifer characteristics are also effective on the likelihood of sinkhole occurrence. These factors, in this research, are studied as exogenous factors. It should be noted that some variables such as water quality, geology status of region, changes of cropping pattern, pumping costs, and utility of region from view point economic and welfare have not been considered.

In order to study the decreasing trend of groundwater level and consequent sinkhole occurrence, possible hypothesis are reviewed as exogenous and endogenous factors in the proposed conceptual model (Figure 3). Mentioned parameters are also shown in Table 2.

Figure 3 Conceptual model and relationship among study variables (see online version for colours)

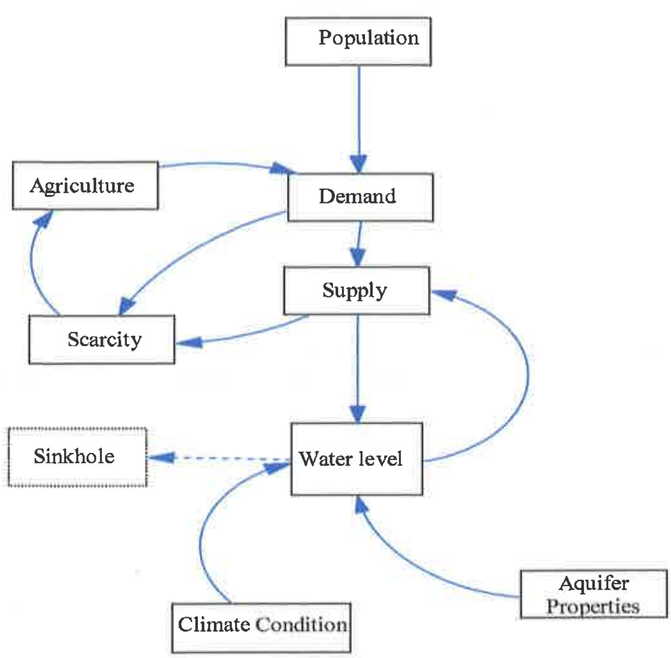


Table 2 The used endogenous and exogenous variables in the model

Endogenous variables	Total water demand, water shortage, cultivation area, groundwater level, population, water supply
Exogenous variables	Climatic variables, aquifer characteristics
Unconsidered variables	Water quality, geology status of region, changes of cropping pattern, pumping costs, and utility of region from view point economic and welfare

2.3 SD approach

SD is an approach to grasp understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. What distinguishes the usage of SD from other approaches is the use of feedback loops and stock and flows (Sterman, 2000; Bazrkar et al., 2013). SD is a branch of systems thinking which provides a simulation tool to model feedback relations in a system. It is a useful tool to study the trends of changes and their causes, to understand the physical process and the flow of information, and to design and simulate the consequences of policies in a system (Bagheri, 2006; Vlachos et al., 2007). The SD tool, Vensim (Ventana Systems, 2004) provides a fully integrated simulation system to conceptualise, document, simulate, analyse, and optimise models of dynamic systems. Vensim provides a simple and flexible way of building simulation models from casual loop or stock and flow diagrams (Khan et al., 2007).

2.4 Dynamic hypotheses

Dynamic hypothesis is a product of insight that the modeller has. It is a dynamic based on two senses

a there is a casual equivalence between structure and behaviour

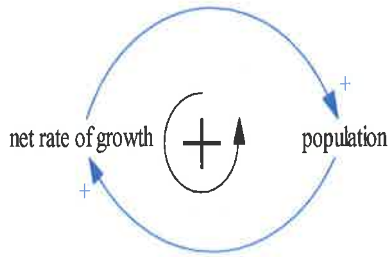
b system behaviour is a function of time.

Since the real system usually contains a great number of loops, many of which do not directly create the important patterns; thus the analyst must eliminate many of the non-dominant loops and variables. The analyst's mental model of the dominant loop structure and how it creates the important time patterns is described in detail in writing. This writing description is called the dynamic hypothesis (Fey, 2004). In this study, causes of sinkhole events in the study area will be presented briefly and generally in three sections include population, groundwater level and cultivation area.

2.4.1 Hypothesis A

Population is always one of the main and effective factors in the operation of water resources. The population increasing affects on drinking water requirement directly, and also both agricultural and industrial water requirements indirectly through the need for food, employment and services. The mechanism of population growth is a reinforcing loop as shown in Figure 4. According to available census, the increasing trend of population is consistent.

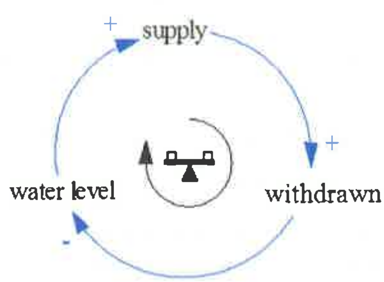
Figure 4 Casual loop of population growth (see online version for colours)



2.4.2 Hypothesis B

The study area has been located in the arid and semiarid climates. There is no surface water resource in the watershed and the groundwater is the only main source of water supply. The drastic decreasing trend of groundwater level and consequent sinkhole events has been caused by the extreme extraction of aquifers. Moreover, due to the drought prevalance in 1990s the status of water table is even more critical. The negative groundwater level in the watershed in the recent two decades has reduced the discharge of the aquifer quantitatively and qualitatively, hence, the water supply has been limited. Total dry-out of 100 wells is reported and confirmed. The mechanism of this event is a balancing loop which the aim of this casual loop is to satisfy the amount of water supply to carrying capacity of the aquifer (Figure 5).

Figure 5 Casual loop of groundwater level (see online version for colours)



2.4.3 Hypothesis C

The agricultural lands have approximately had a downward trend since 1996. But in recent years, this trend has somewhat increased and then stabilised and simultaneously with this process, the groundwater level has dropped. On the other hand, based on the available data, water withdrawal from the aquifer has not reduced considerably and continuously. The reason is that although the area under cultivation has decreased, but the cropping pattern has also changed (development of orchards especially pistachio) in the study area. As regards, the water requirement of fruit trees (e.g., for pistachio is 11,370 m^3/hectare) is far more than the water requirement for yielding products as corn (e.g., for wheat is 6,250 m^3/hectare). Therefore, the water withdrawal is not only decreased, but also has increased in some years. Whilst, water shortage does not occur due to the abounding of water supply, cultivation area will increase. Consequently, this increase leads to the rising of water supply and demand, then, these casual relationships create a reinforcing loop (Figure 6). But when, due to the failure of water supply, the total demand is faced with water shortage, so the balancing loop is activated. This condition will reduce the cultivation area which it is affected by a reduction in the water supply due to dropping of the water table.

Figure 6 Cultivation area casual loops (see online version for colours)

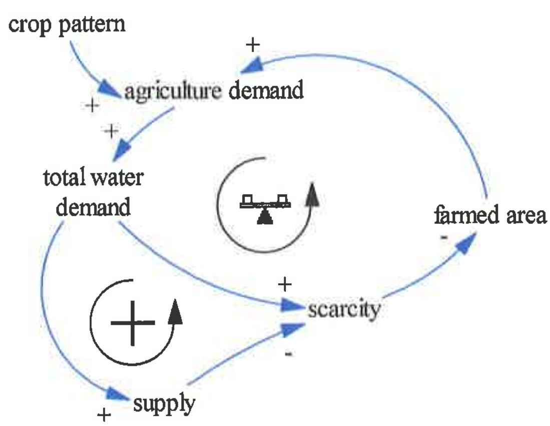
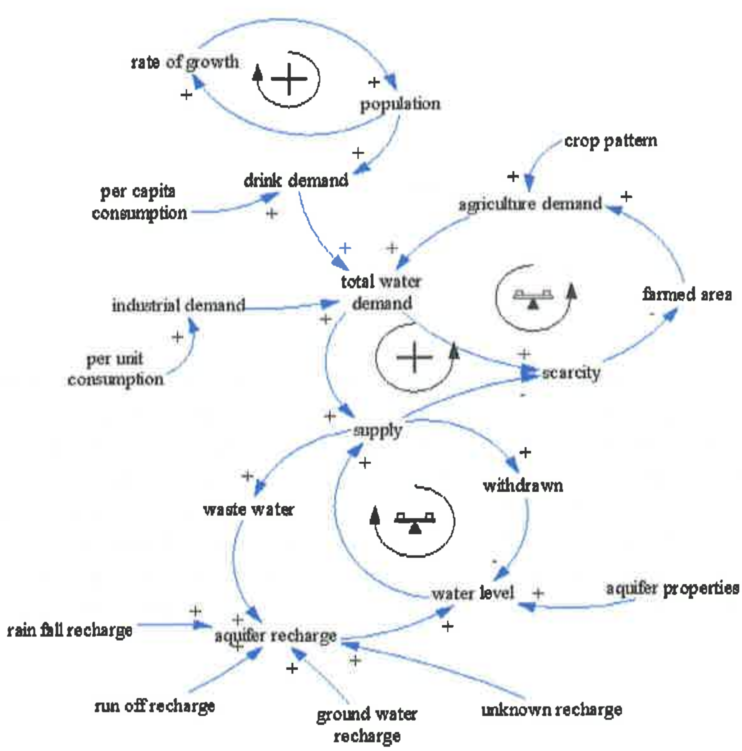


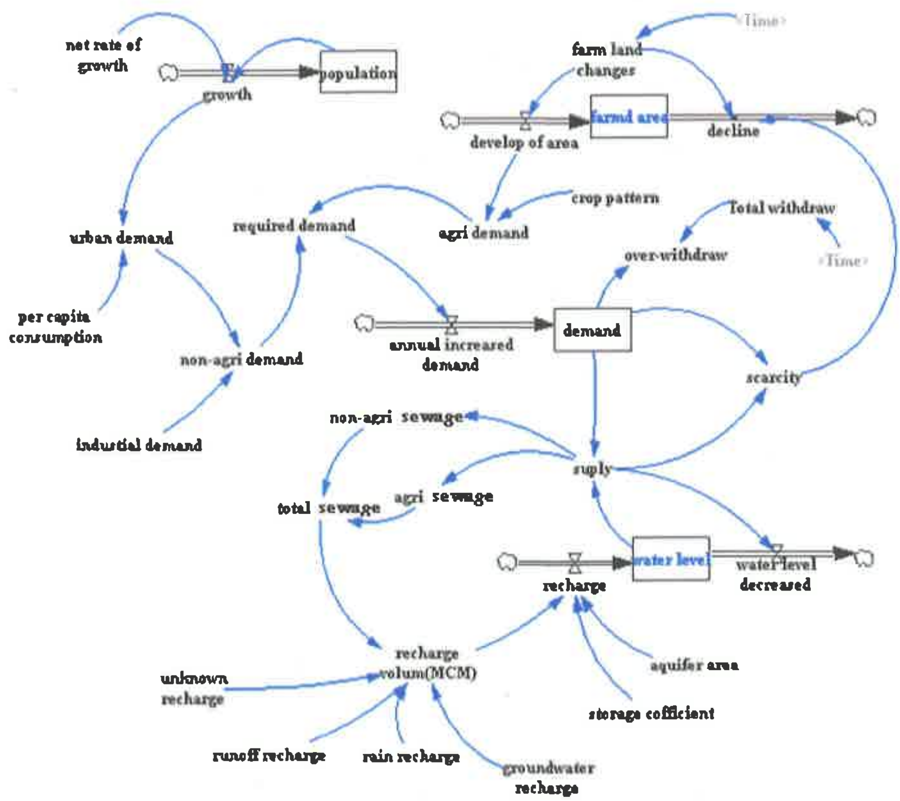
Figure 7 Total casual loop (see online version for colours)



2.5 Total casual loop and stock and flow diagram structure

Dynamic hypotheses are gathered in Figure 7. This total casual loop presents the governing mechanism in relation to watershed sinkhole events. Each factor was described in previous sections. The stock and flow diagram, as the total structure of a model, is also shown in Figure 8.

Figure 8 Stock and flow diagram structure of model (see online version for colours)



In this model, based on the census in 1996 (base year), the county's population is 40,617 with an average growth rate 1.1% and, the area of the agricultural land in the base year is 17,400 hectares. The time series of cultivation area was introduced to model according to available data (Ministry of Energy, 2006). In order to estimate the water requirement per area unit for total cultivated yields in plain was used by NETWAT software (Valipour, 2012). This software is a computer program for the calculation of crop water requirements in Iran and developed by ministry of agriculture and meteorological organisation of Iran. Table 3 shows the major yields, water requirement and cultivation area in the study area.

Table 3 Characteristics of cultivated yields for the study area

Name of yield	*Net water requirement (m^3/hectare)*	*Cultivation area (hectare)*
Pistachio	11,370	2,030
Apricots	8,330	850
Pomegranate	9,010	360
Grape	5,880	300
Wheat	6,250	6,400
Barley	5,420	200
Alfalfa	1,090	2,200

Drinking water demand is also calculated by multiplying of drinking per capita for each person (53 m^3/year for each person) in population. In addition, the annual water consumption has been considered about 462,000 m^3 for the industrial sector. The total annual water demand is the sum of the agricultural, industrial and drinking water demand, which consider as input rate variable for the demand state variable. The total water demand for base year (1996) is equal to 1,438.7 MCM which its change rate is proportionately calculated by change rate of population, cultivation area and industrial demand and in its input rate variable is applied.

Water shortage is the lack of sufficient available water supply to meet the demands of water demand within a region. Water shortage impresses the cultivation area so that the area under cultivation reduces according to mean water requirement of yields per unit area. In order to compute the drawdown of groundwater level due to water extraction was used of equation (1).

$$H = S/(A \times SC) \tag{1}$$

In this equation, H is the water level drawdown, S is water supply, A is the area of the aquifer and SC is the storage coefficient. State variable of water level has an input rate variable (aquifer recharge) and an output rate variable (aquifer discharge).

2.5.1 Recharging factors of aquifer

Affecting factors on the inflows to the aquifer include deep percolation due to drinking, industrial and agricultural water consumption, precipitation, runoff and recharges of groundwater.

2.5.1.1 Groundwater recharge

In order to estimate the volume of inflow, the average length of cross sections and average slope of groundwater movements was calculated using elevation map and available data (Ministry of Energy, 2006) and consequent, the transmission coefficient for each cross section was estimated and then, the annual water volume was totally computed about 30.56 MCM.

2.5.1.2 Deep percolation resulting from various uses (waste water)

1 The conventional irrigation system of the study area is surface irrigation and this irrigation method has the high losses. On the other hand, the dominant cropping pattern is moving toward cultivation of pistachio trees which have the high water consumption. Therefore, the mentioned reasons increase the water losses and consequent, according to the water balance results that adopted from Yazd Regional Water Authority (1994) report, about 25% of water consumption in agriculture sector return within the aquifer.

2 Since the waste water disposal of drinking, industrial and hygiene, mainly is conducted through absorption wells, therefore, it can consider about 60% of consuming water volume in three mentioned sectors as recharge of aquifers (Yazd Regional Water Authority, 1994).

About 90% of total water consumption is used in agriculture sector and only 10% is consumed in other sectors. Hence, according to the descriptions of two previous sections, the total deep percolation is calculated as follows [equation (2)]:

$$TP = WS \times (0.25 \times 0.90 + 0.10 \times 0.60) \tag{2}$$

where TP is the total deep percolation and WS is the total supplied water.

2.5.1.3 Aquifer recharge using floods and surface runoffs in water balance boundary

Sometimes due to natural factors, the flood occurs. A climatic factor like rainfall is also effective on the likelihood of flood occurrence So that, short-term rainfall with high intensity leads to runoff and flood events (Bazrkar et al., 2013). In this study, according to the report of the Yazd Regional Water Authority (1994), the recharge amount of aquifer due to flood occurrence has been estimated about 11 MCM.

2.5.1.4 Rainfall recharge

The long-term mean annual precipitation for 11 years (from 1996 to 2006) in the study area is 72.2 mm that is shown in Table 4.

Table 4 Mean annual precipitation of the study area

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*Mean*
Precipitation (mm)	47.8	23.4	76.9	14.5	82.8	148	54.1	156	67	45.4	78.9	72.2
Percolated water volume (MCM)						3.87						

But, due to the high evaporation, topographic slope and also the movement of runoffs toward downstream of the watershed, the direct percolation in water balance boundary is very low. So, according to the report of the Yazd Regional Water Authority (1994), only 1% of precipitation recharges the aquifer. Thus, the volume of this kind of recharge for aquifer is like equation (3):

$$RP = P \times A \times 0.01 \quad (3)$$

where *RP* is the abbreviation of recharge due to precipitation, *P* is the long-term mean annual precipitation and *A* is the area of plain. Hence, according to the above descriptions, the water volume of percolation due to precipitation is about 3.87 MCM.

2.5.1.5 Recharge using unknown factors

Some unknown factors in order to recharge of aquifer such as the operating hours of water wells, soil type, cropping pattern, irrigation periods, the amount of recharge of aquifer in watershed upstream and so on, have not been considered in this study. But, these factors have a total volume about 6.27 MCM that recharge the aquifer and are considered as unknown factors.

2.5.2 Discharger factors of aquifer

2.5.2.1 Underground outlet

The only underground outlet of this plain has been located at the out-of-the-way point in the northeastern side of plain boundary. The estimated water volume of underground outlet was computed about 0.274 MCM.

2.5.2.2 Outflows due to withdrawal from the aquifer

The most important outlet of the aquifer includes wells and Qanats in the watershed. There is the number of 469 deep wells, 314 semi deep wells and 36 Qanats. On average, about 159.3 MCM of water annually are extracted from the aquifer by people (Table 5).

Table 5 Outflows due to withdrawal from the aquifer by wells and Qanats

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*Mean*
Withdrawal (MCM)	154	154	158	159	155	155	167.9	159	155	157.7	178.1	159.3

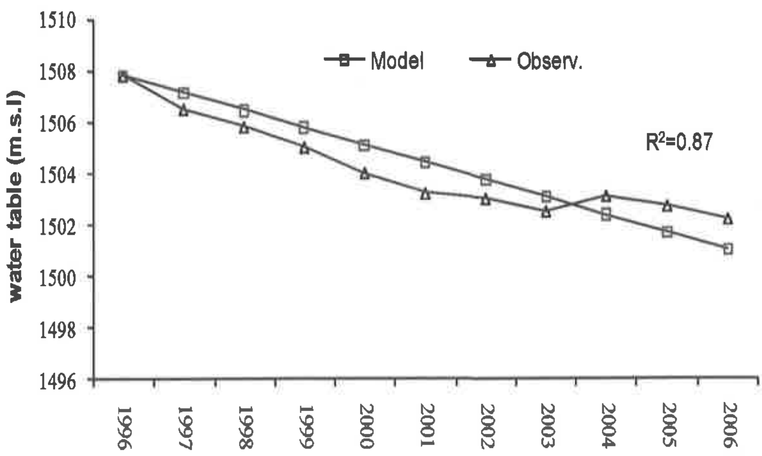
It should be noted that the introduced dimension of inflows and outflows data is cubic meters. On the other hand, population, cultivation area, water demand and groundwater level were identified and applied as state variables and, the net population growth, cultivation area development, annual water supply, inflows and outflows to aquifer as rate variables.

3 Results and discussion

3.1 Verification of model

After running the model for 11 years (from 1996 to 2006), in order to evaluate the model verification, observed and estimated values of groundwater level of Abarkuh County Watershed was plotted (Figure 9). As it is obvious in the figure, the determination coefficient is equal to 0.87 (the correlation coefficient is higher than 0.90), in other words, this result relatively shows the good validation and accuracy.

Figure 9 Observed and estimated groundwater level (see online version for colours)



3.2 Results

The model outputs such as total demand, urban demand, cultivation area, water supply, groundwater level, water shortage, over withdrawal, and population growth for 25 years from 2006 to 2021 are presented in Figure 10(a)–10(h), respectively.

Figure 10 Output plots of model (see online version for colours)

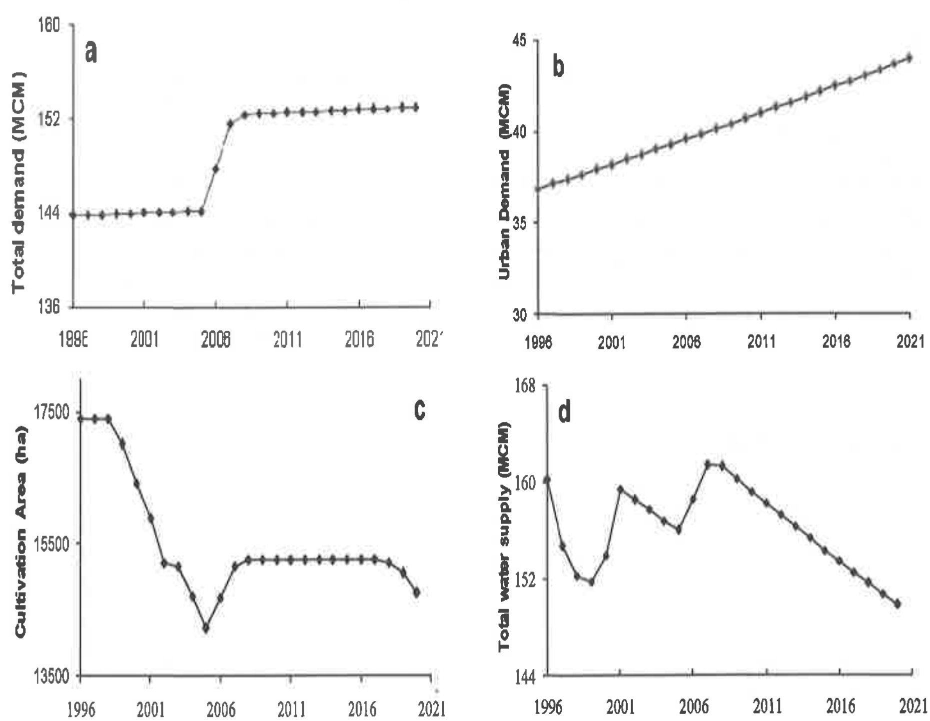
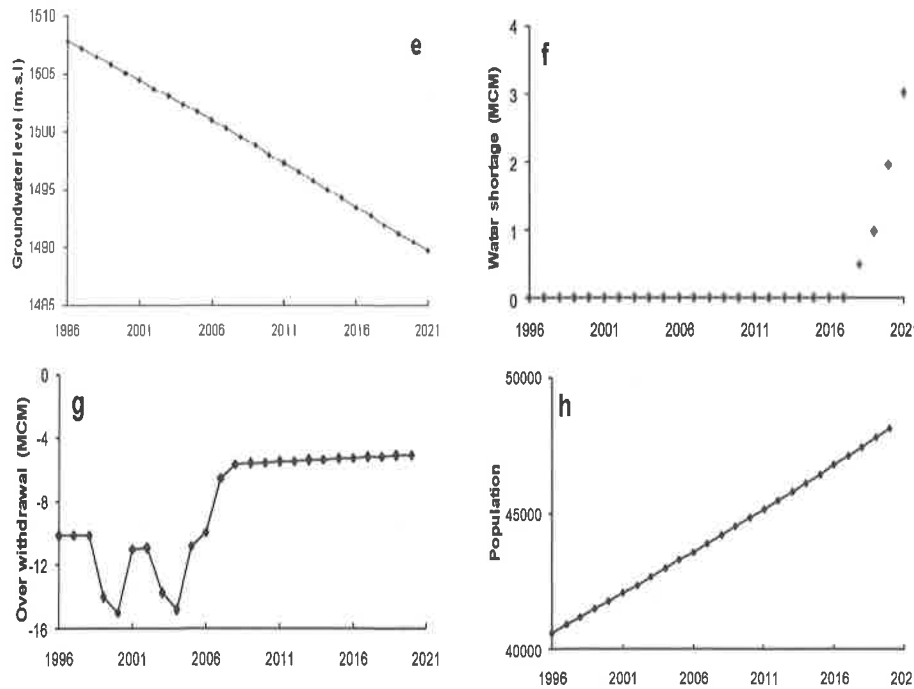


Figure 10 Output plots of model (continued) (see online version for colours)



The results showed different behaviours in these variables. Therefore, as shown in this figure, the over withdrawal displays an increasing trend during the simulation period [Figure 10(g)]. This means that the withdrawal from the aquifer is consistently more than the water requirement due to an increasing trend of population growth [Figure 10(h)]. Moreover, the results of the model show the lack of water shortage during the 1996–2006 [Figure 10(f)]. Since, in order to supply the total water demand, the requirements have consistently been extracted from the aquifer. Also, area under cultivation decrease at the end of the simulation period [Figure 10(c)], and it is because of a decrease of water supply [Figure 10(d)] due to reduction in groundwater levels [Figure 10(e)]. On the other hand, the total demand has sensibly increased during a period of 25 years [Figure 10(a)]. Although, the cultivation area has decreased at the end of period but, because of an increase in urban demand [Figure 10(b)], the total demand trend is continuously upward.

3.3 Sensitivity analysis

Sensitivity analysis is applied in order to detect the factor(s) that have the most effective impact on the model and their changes has considerable effect on the results of the model. In other words, the model for that variable is more sensitive that other variables and it is necessary to its calculation with more precise. In this study, the effects of three variables such as cropping pattern, per capita consumption of drinking water and runoff recharge on the groundwater level were investigated. The groundwater level variations as the result of an increase as equal as 10% for runoff recharge variable and, a decrease as equal as 10% for two other variables are shown in Table 6. The results of the model showed that cropping pattern, runoff recharge and per capita consumption of drinking water have the most effect on the groundwater level, respectively, in comparison with groundwater level in 2006.

Table 6 The results of sensitivity analysis of three key variables on groundwater level

Variable	*Crop pattern (–10%)*	*Per capita consumption of urban demand (–10%)*	*Runoff recharge (+10%)*	*Without change*
Groundwater level in 2007 (m)	1,502	1,500.3	1,500.4	1,500.29

3.4 Investigation of management scenarios

In order to adopt the appropriate management strategies for preventing the more droppable of the groundwater level and an increase of water level, the four possible different scenarios were applied. These scenarios are briefly described as follows:

- Scenario A

  In this scenario, a conditional option was applied within the model so that, the water withdrawal is not more than water requirement. By applying this scenario, the results showed that water level increases about 2.9 m in comparison with the lack of the use of the scenario at the end of the 25 year period (Table 7).

- Scenario B

  In this scenario, it was assumed that through using modern irrigation systems we can reduce the water requirements to 6,000 cubic meters per hectare for crops. So that, by applying this approach during the 2006 to 2021 period, the water level increase about 8.44 m at the end of the simulation period (Table 7).

- Scenario C

  If it was applied in four main sinkholes that have occurred in the watershed as resources for artificial recharge, and aquifer recharged using floods, then water level would increase about 3.5 m at the end of the simulation period (Table 7).

- Scenario D

  If it was assumed that the per capita of drinking water consumption is 150 m^3/year, it should be noted that this per capita is one of the fifth development plan objectives, ground water level slightly increases about 0.05 m at the end of the simulation period (Table 7).

Table 7 Comparison of groundwater levels under different management scenarios

Scenario ID	*A*	*B*	*C*	*D*
Before apply scenario (m)	1,489.2	1,489.2	1,489.7	1,489.7
After apply scenario (m)	1,492.1	1,497.6	1,493.2	1,489.75
Groundwater level increasing (m)	2.9	8.4	3.5	0.05

3.5 Discussion

As it is observed in Table 7, a decrease in cultivation area, as a used scenario, has the most effective impact in increasing groundwater level. After that, decreases in water requirement of agricultural yields, artificial recharge and prevention of over withdrawal have had the most effects on the water level increasing, respectively. The second scenario has had the most effective impact in increasing of water level because more than 90% of water withdrawal from the aquifer in Abarkuh region is used in agriculture sector. Therefore, it can be concluded that the management practices in agriculture sector in order to reduce the water consumption per unit area, will have most effect on improvement of aquifer status. This scenario is possible if by reducing water consumption per unit area, simultaneously the water rights of farmers also proportionally reduced. Moreover, if all mentioned scenarios were together applied, the model would show the better and more effective results and consequently the water table would retrieve.

4 Conclusions and suggestions

It is not possible to prevent sinkhole occurrence and its damages perfectly, therefore, we have to adjust to this event and change the threat to an opportunity. Despite the continuously decreasing trend of groundwater level of Abarkuh aquifer and consequent sinkhole occurrence in the watershed, hazardous sinkhole events are preventable.

In the present study, the impacts of the population growth, withdrawal of groundwater and cultivation area variables on the water table of the aquifer and consequent occurrence of sinkholes were discussed and modelled using the SD approach in Abarkuh County Watershed. As mentioned before, the drawdown trend of the groundwater level has the most effect on sinkhole events and consequent, this event poses a serious problem for Abarkuh County Watershed of Iran.

The results of simulation model present that the current trend of water consumptions and over withdrawal is causing the drawdown trend of the water table. So that from early 1980s to 1996, groundwater level has fallen about 8 m and, this event has been led to the occurrence of four sinkholes in the study area between 1993 and 1996 years. From 1996 until the recent sinkhole event (S-2009), the groundwater level has fallen about 8 m as well. The continuation of this process increases the occurrence probability of the larger and deeper sinkholes in the next decades. Therefore, four scenarios in order to prevent the drawdown trend of groundwater level were considered and the effects of each of them on water level were investigated as well. Among of these scenarios, the scenario of water requirement reduction of agricultural yields from 7,739.5 to 6,000 m^3/ha had the most effect. Furthermore, extension of artificial recharge and the lack of the water withdrawal more than requirement scenarios have relatively had good effects on groundwater level increasing. But, the reduction of per capita consumption of urban demand to 150 litres per day had a slight effect on the water table of the aquifer because of more than of 90% of water consumption is related to agriculture sector.

In general, the management strategies that are applied to improving the aquifer status have to reduce the water consumption in all sectors especially in the agriculture sector. So, as some suggestions, at the first time, it should be prevented from the over withdrawal and then, the modern irrigation systems were developed. Also, in addition to the mentioned strategies, the other strategies such as the cultivation of plants adapted to growing in saline conditions and resistance to water stress and artificial recharge increasing using the existing stream flows can be effective in the study region. If the mentioned strategies were applied, it is prevented from the drawdown trend of groundwater level and consequent from the occurrence of deeper and larger sinkholes. Hence, it can more realistically simulate the aquifer status using SD approach and by considering these suggestions.

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