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Assessment of effects of changes in landuse on the water balance components using SWAT (Case study: Doroudzan dam basin)

Y. Shokouhifar[1], H. Zarei[2*], A. M. AkhondAli[3] and A. Khormian[4]

1-MSc Graduate in Department of Hydrology and Water Resources, Faculty of Water and Environmental Engineering, Shahid Chamran University of Ahvaz. Iran.
2- Corresponding Author, Associate Professor, Department of Hydrology and Water Resources, Faculty of Water and Environmental Engineering, Shahid Chamran University of Ahvaz. Iran. (zareih@scu.ac.ir).*
3- Professor, Department of Hydrology and Water Resources, Faculty of Water and Environmental Engineering, Shahid Chamran University of Ahvaz. Iran.
4- PhD Graduate in Water Resources Management, Faculty of Civil Engineering, Khajeh Nasir al-Din Tusi University of Technology.

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Abstract

In this study, to investigate the effects of land use changes on hydrological components of the Doroudzan Dam basin for the three periods of 1979 to 1990, from 1987 to 1999, and from 1997 to 2006, three land use maps for the years 1986, 1996 and 2005 were prepared. Then, using the semi-distributed SWAT model, the basin hydrology processes were simulated. After calibration to validate the model, validation was performed for each period. The Nash-Sutcliffe coefficient in calibration and validation of the first period was 0.74 and 0.52, in the second period was 0.88 and 0.61, and in the third period was 0.83 and 0.8, respectively. Also, three scenarios were defined to determine the effect of each land use management application in the study time step (1979 to 2006). All the scenarios were simulated under the same conditions for rainfall and temperature and different land use maps. The impact of land use change under these scenarios is well observed, with the latter having a 27.7% decrease in surface runoff compared to the control scenario, as rangeland, forest, agricultural cover increased, wasteland decreased. Has found. In the third scenario, surface runoff decreased by 13.5% compared to the control scenario, but increased compared to the second scenario, as rangeland cover decreased and wasteland increased.

Introduction

well as for the climate system of any region on earth. Therefore, it is essential to study the effect of human activities on the water cycle and the environment (Anvar, 2010). Land use changes in the country's basins as one of the most important human factors causing changes in the resources and uses of basins, which is necessary for the country's water management (Hosseinzadeh, 2014). In recent decades, population growth, urban development and intense agricultural activities, reduction of rangelands, and deforestation with changes in land cover patterns and land use have caused concern in water resources and ecosystem management (Mango et al. 2011). Changes in land cover and land use are the most important factors affecting the quantity and quality of

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water, which in addition to changing the water balance in basins, increases soil erosion, which leads to the entry of large amounts of sediments and nutrients into rivers (Schönbrodt et al. 2010). Hydrological models are the basis for recognizing the cause and effect relationship between hydrological changes and land use changes (Karamoz et al. 2009). Today, the SWAT model is used worldwide to evaluate the effect of land use change on the basin's hydrology. Ghodousi et al. (2014) used the SWAT model to investigate the effect of land use change on the entrance of the Aji Chai River to Lake Urmia. Using Landsat images from 1976, 1989, 2002, and 2008 as input to the SWAT model and the model for the years 1976 to 2008 was implemented every month. The results showed that the volume of water leaving the basin decreased by 51% and actual evapotranspiration increased by 13%, during which land use changes have played an important role in reducing the water area of Lake Urmia. Kundu et al. (2017) investigated the effect of land use change on water balance in a part of the Narmada River Basin in India using the SWAT model. Land use changes in 1990, 2000, and 2011 were analyzed and the Markov chain model was used to predict future land use changes (2020, 2030, 2040, and 2050). The results showed that during the period 1990 to 2050, the value of the CN increased due to the decrease in vegetation and the increase of agricultural lands and residential areas, which increased runoff and decreased actual evapotranspiration, as well as decreased groundwater area s. Baker et al. (2013), in assessing the impact of land use on water resources in East Africa using the SWAT model, reported that land use change in the highlands of East Africa has led to an increase in surface runoff combined with a decrease in groundwater recharge, which this reduction Groundwater recharge can have detrimental effects on people living in the basin and pose a threat to the wildlife of Lake Nakuru National Park. Wagner et al. (2013) evaluated the effect of land use change on water resources. They stated that although the increase of agricultural lands and urban development has not significantly changed the water balance at the farm scale, at the basin and sub-basin scale, significant changes in Hydrology and water balance have been created in such a way that with the development of urbanization, the amount of water has increased by about 7.6% and evapotranspiration has decreased. Meanwhile, the development of agricultural lands has the opposite effect and has reduced the amount of water and evapotranspiration has increased by 5.9 percent. Shi et al. (2012), in a study using the SWAT model, reported that the combined effect of land use change and climate change has increased surface flow, evapotranspiration and river flow. Climate change, meanwhile, has increased surface and river flow, reduced actual evapotranspiration, and land use has played a reciprocal role, although the effects of climate change are greater. Mango et al. (2011) used the SWAT model to investigate the effect of land use change and soil cover change on the discharge of the Nyangores River in Kenya. They simulated runoff and sediment under three different scenarios, including: minor change in land use and conversion to agricultural land, a complete change of land use and conversion to rangeland, and complete change in land use and conversion to agricultural land, and report The conversion of forest use to agricultural and rangeland reduced the amount of flow during the dry season and also increased peak flow and sediment load, intensified erosion in the hills, and reduced water deficit at times of the year when water was limited in the basin. Hosseini et al. (2015) simulated and compared the effects of different uses on water balance components using the SWAT soil and water evaluation model. The simulation results in Shekastian basin showed that out of the total average rainfall of 510 mm, the highest amount belongs to evapotranspiration in the basin.the total groundwater and subsurface water flow is equal to 43 mm (8.4%). 8.4% is a good potential for field planners to implement management programs. Ghaffari et al. (2009), in a study in Zanjan River Basin, pointed out that hydrological responses such as runoff, groundwater status, sediment load, river flow, evaporation, and transpiration, etc. to changes in land use have a limited threshold. They reported that the hydrological response to land use change in this basin was non-linear, so that by simulating a 60% reduction in rangelands using the SWAT model, it was observed that runoff had increased significantly. He also stated that from 1967 until the research, a 34% reduction in rangelands and conversion to urban areas, rainfed agricultural lands, and barren lands, caused a 33% increase in surface runoff and a 22% decrease in groundwater in the Zanjan watershed river. Due to the above introduction and the high impact of land use changes on different components of the water cycle in basins, the purpose of this study is to investigate the impact of land use change on runoff and other components of the basin area of Doroudzan Dam. It supplies agricultural water to 112,000 hectares of downstream lands and the environmental water needs of Bakhtegan Lake (the second largest lake in Iran).

Materials and methods

Study area

Doroudzan dam basin, with an area of 4342 square kilometers, is located in the southwest of the country and the north of Fars province. It is located in the geographical range of 51 degrees and 42 minutes to 52 degrees and 54 minutes east longitude and 30 degrees to 30 degrees and 59 minutes north latitude. Up to 95% of the basin area is located in Fars province and the rest (5%) is located in Kohkiluyeh and Boyer-Ahmad provinces. In terms of height, the highest point of the basin is 3708 meters, and the lowest point of the basin at its output is 1627 meters above sea area, and the height difference between the lowest and highest point of the basin is 2081 meters. The length of the main river of the basin is about 150.2 km, and after crossing the plains, it finally flows into Doroudzan Dam Lake. Figure (1) shows the location of the study area in Iran and Fars province.

SWAT model theory

The SWAT model stands for "Water and Soil Assessment Tool", first developed and established in 1990 by Dr. Jeff Arnold (Dolatabadi et al. 2013). The SWAT model is a semi-distributed model that has a physical basis. In other words, this model can estimate the flow of basins by using the hydrological cycle and formulating all physical processes (Demirel et al. 2009). The SWAT model first divides the basin into several sub-basins and each sub-basin into several units of hydrological response (HRU) based on topography, land use and soil, and thus the hydrological processes for each Hydrology unit are determined individually and then quantified for the entire basin (Arnold et al. 2012). The hydrological simulation of the basin in the SWAT model can be divided into two general parts: the terrestrial phase and the aqueous phase. The terrestrial phase is related to surface processes and the entry of water, sediment, and chemical elements into the main waterway of each sub-basin. The aqueous phase simulates the processes of streams and canals, including the movement of water, sediment, and chemicals (Neitsch et al. 2011). The simulation of the terrestrial part of the hydrological cycle in the SWAT model is based on the water balance (Equation 1):

$$SW_t = SW_o + \sum_{i-1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad (1)$$

Where SW_t is the final soil water content (mm H2O), $SW0$ is the initial soil water content on day i (mm H2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H2O), Q_{surf} is the amount of surface runoff on day i (mm H2O), E_a is the amount of evapotranspiration on day i (mm H2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H2O), and Q_{gw} is the amount of return flow on day i (mm H2O).

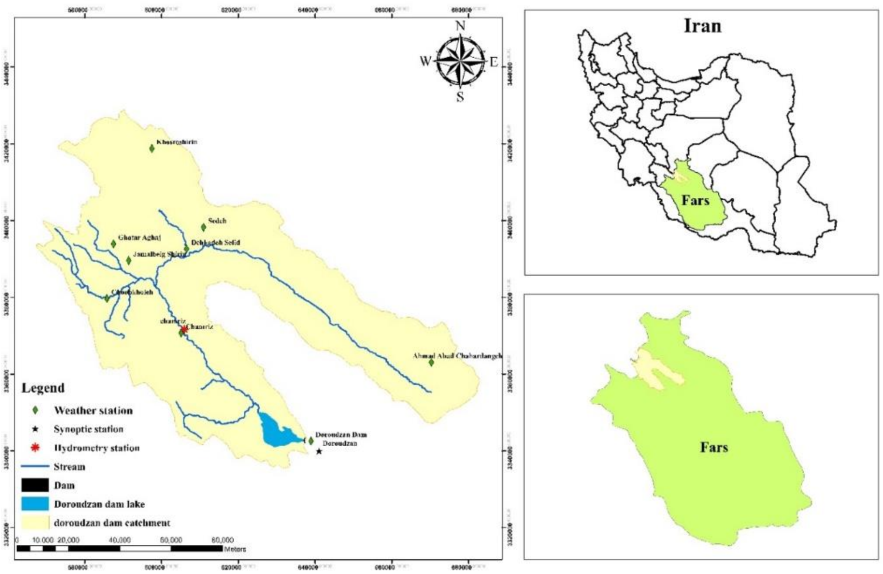

Fig. 1- Location of the study area in Iran and Fars province

Modeling of hydrological conditions using SWAT model

Since the purpose of this study is to investigate the hydrological impact of Doroudzan Dam basin area from land use changes in the past decades, images of TM and ETM + Landsat satellite were used to prepare the required land use maps in 1986, 1996, and 2005. From atmospheric corrections to satellite images in ENVI software, image classification using a maximum probability algorithm with acceptable accuracy in seven user classes, including barren lands, agricultural lands, gardens, rangelands, residential areas, forest lands, and lakes, were surveyed. Three different SWAT models were designed for the Dodroudzan dam basin. The first model in the period 1979-1990 from the land use map of 1986, the second model in the period 1987-1999 from the land use map of 1996 and the third model in the period 1997-2006 from the land use map of 2005 were used. In the first stage, with the introduction of the Dem map with an accuracy of 30 meters and the production of the flow network by the model itself, based on the threshold of 14,000 hectares as the minimum drainage area and the introduction of the Chamriz hydrometric station as basin output, the dam was divided into 11 sub-basins. After drawing the boundary of the basin, sub-basin and flow network, the physical parameters of the basin and each sub-basin, including: area, length of the main waterway, slope, elevation characteristics etc, are calculated. In the next step, soil and land use maps were entered into the models, and, slope classes were defined, and combined with them, hydrological response units (HRU) were generated in each sub-basin. In this study, three slope classes (0-9.5, 9.5-24, 24<%) were introduced to the model. The next step is to introduce climatic data to the model. Daily precipitation and temperature data were entered into the models according to Table (1), and the Hargreaves-Samani method was used to calculate the potential evapotranspiration. The variable storage coefficient method was used for flow routing. In the final step, the model was implemented to simulate the monthly runoff with three years of training for all three models. Also, Chamriz station monthly flow statistics model was used to calibrate and validate. Table (1) presents the specifications of meteorological stations used in the SWAT model.

Calibration and validation of the SWAT model

In this study, first by SWAT-CUP software and by performing sensitivity analysis by comprehensive sensitivity analysis method, the parameters that had the most sighnificant impact on the outflow of the basin were identified. Among the 29 parameters studied in this study, the model showed sensitivity to 19 parameters, and was identified as influential variables in runoff simulation in the study basin. After performing the sensitivity analysis step using SWAT-CUP software, the SUFI-2 algorithm in SWAT-CUP software was used to calibrate the model. For calibration, for the first period of monthly discharge data measured at Chamriz station (1982-1989), the second period (1991-1998), and the third period (2000-2005) for calibration and for validation, the first period (1990), The second period (1999) and the third period (2006) were used, and the Nash-Sutcliffe coefficient was used as the objective function for optimization. Explanation coefficient (R^2) and Nash-Sutcliffe (N-S) indices were also used to evaluate the model performance in the calibration and validation stages. In order to reveal the effect of land use change on the hydrological components of the basin, a scenario was defined for each land use map. The scenarios were considered equal to 26 years (1979 to 2006) in terms of climatic data.

Results and discussion

Investigating land use changes

Land use maps for 1986, 1996, and 2005, which are shown in Figures (2) and (3) respectively. The area of each use and the percentage change of each period are presented in Table (2). For better representation, the uses in the three groups, A, B, and C, are shown on the diagram. The use of gardens and agricultural lands during the years 1986 to 2005 in the entire basin area of the dam due to increased irrigation, rice cultivation, and human needs have increased and residential areas have gradually increased, during the first period to the third has changed 878%. This is due to the increase in population and villages over time. Also, the water area of Doroudzan Dam Lake has an increasing trend from 1986 to 1996, which is due to the rainy season this year, but has gradually experienced a decreasing trend from 1996 to 2005. Range and forest land use increased from 1986 to 1996 but decreased from 1996 to 2005. Finally, barren lands decreased sharply from 1986 to 1996, but from 1996 to 2005, it gradually increased. Changes in forest use during the second to the third period have been declining, which can be due to deforestation and change of forest use to agricultural land or weakening and conversion of forest into rangeland, garden, and residential areas. Rangeland use during the 20 years and also during the first three, second and third periods first had an increasing trend and then a decreasing trend, which is due to the conversion of rangelands into agricultural lands and the construction of gardens and may be due to climate change in the region and drought to barren lands.

Table 1- The character of meteorological stations in the Doroudzan Dam basin area

Row	Station Name	Station Type	Latitude	Longitude	elevation	Year
1	Ahmad Abad Chahardangeh	Rain Gauge	30°23´21	52°41´26	2233	2006-1979
2	Jamalbeyg Shirin	Rain Gauge	30°36´30	51°57´21	2010	2006-1979
3	Chamriz	Evaporation Gauge	30°27´57	52°05´40	1789	2006-1979
4	Choobkholeh	Rain Gauge	30°32´51	51°53´58	2056	2006-1979
5	Khosroshirin	Rain Gauge	30°54´5	52°00´39	2340	2006-1979
6	Dehkadeh Sefid	Rain Gauge	30°42´55	52°04´59	2181	2006-1979
7	Sedeh	Evaporation Gauge	30°43´10	52°09´48	2192	2006-1979
8	Ghatar Aghaj	Rain Gauge	31°43´12	51°53´24	2306	2006-1979
9	doroudzan dam	Synoptic	30°10´25	52°27´46	1650	2006-1979
10	Chamriz	Hydrometry	30°27´	52°08´	1840	2006-1979

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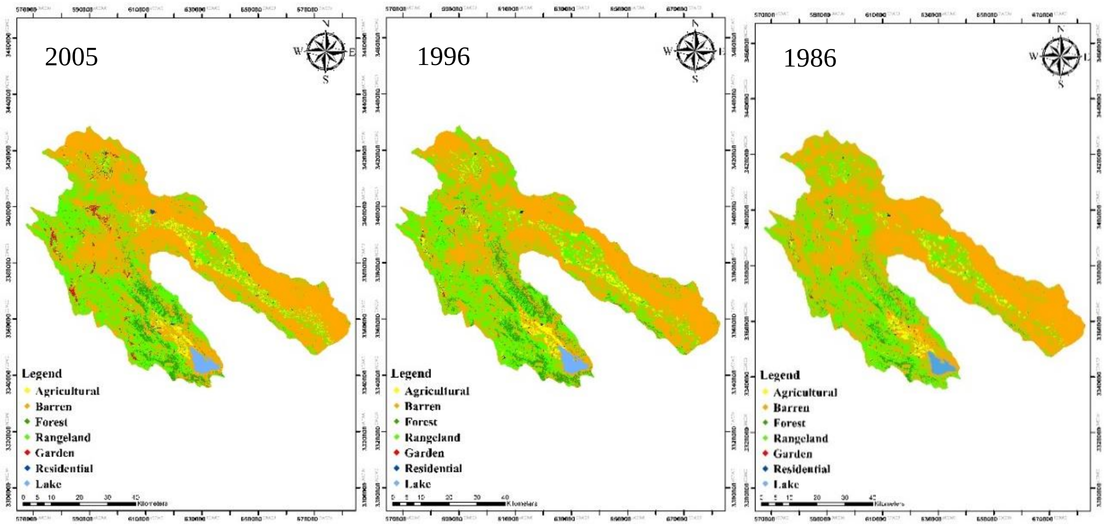

Fig. 2- Land use maps of Doroudzan Dam basin

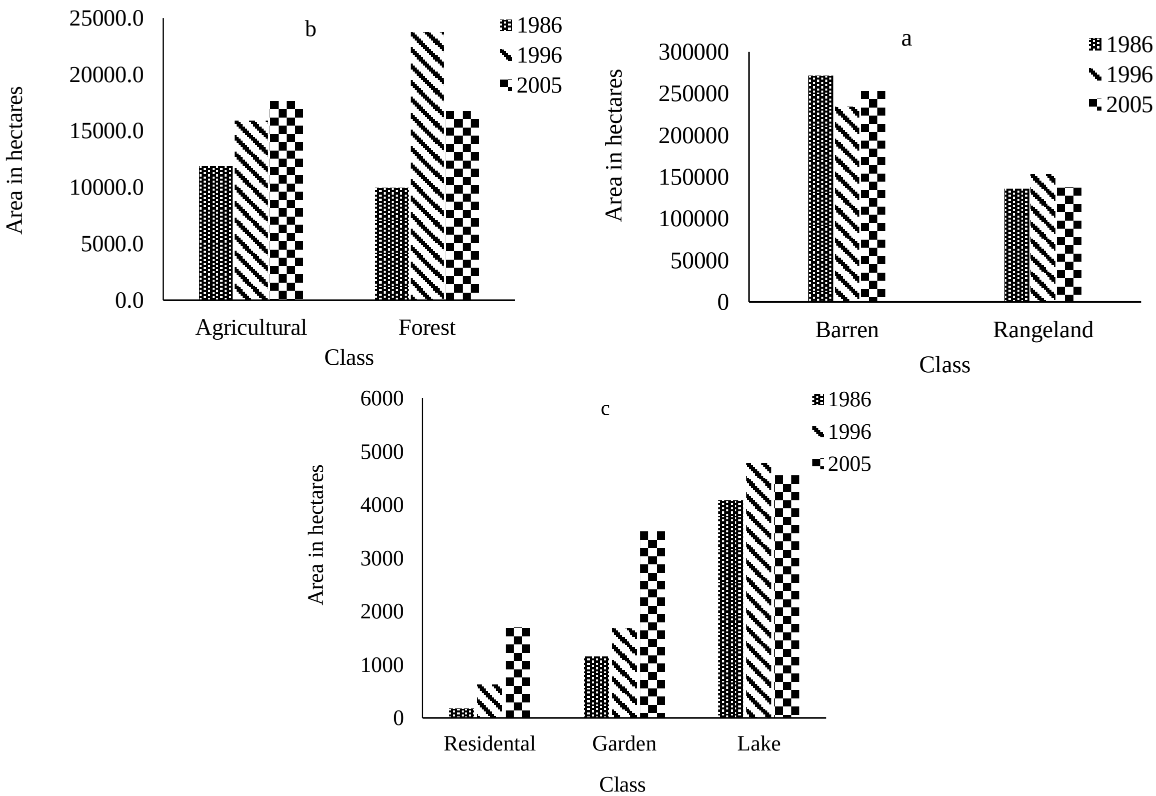

Fig. 3- Land use changes in the studied periods a) Barren land and rangeland, b) Agriculture and forest, c) Residential, garden, and lake.

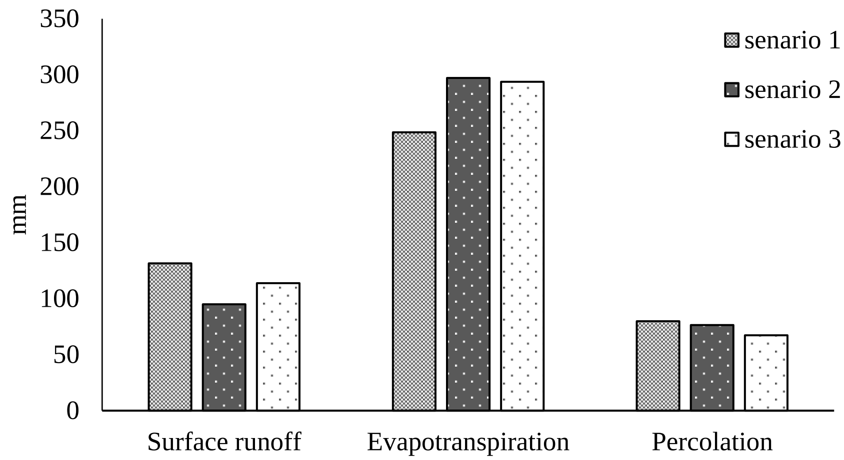

Fig. 4- Changes in hydrological components in scenarios in millimeters

Table 2- Doroudzan basin area using maximum probability and percentage of changes

Row	Class	Area in hectares			Percentage of changes		
		1986	1996	2005	1986-1996	1996-2005	1986-2005
1	Residental	173	628	1690	264	169	879
2	Agricultural	11884	15914	17632	33.9	10.8	48.4
3	Barren	271131	234090	252800	-13.7	8.0	-6.8
4	Forest	9937	23730	16748	138.8	-29.4	68.5
5	Garden	1154	1680	3497	45.6	108.1	203.2
6	Lake	4076	4788	4549	17.5	-5.0	11.6
7	Rangeland	135829	153322	137275	12.9	-10.5	1.1

Sensitivity analysis of parameters, calibration, and model validation

Based on the results of the sensitivity analysis of the model, 19 parameters were identified as the most sensitive parameters, the results of which are presented in Table (3). The infiltration curve parameter in medium humidity conditions (CN2) has the most sighnificanteffect on the outflow from the basin. After CN2, the parameters ESCO and SOL_AWC, the coefficient of compensation of soil evaporation and the average water uses in the surface layer, respectively, are in the next rank. After the sensitivity analysis stage, with the help of SWAT CUP software and monthly discharge statistics in Chamriz station, the model was calibrated and validated. An important point was noted; That these steps be performed separately for years close to the user map under review. For example, for calibration of the model, based on the land use map of 1986 (first period), the years 1981 to 1989 should be considered. This view was based on the approach used by Koch (2011). Finally, the model was evaluated using two coefficients of explanation coefficient (R^2) and Nash-Sutcliffe coefficient (N-S), the results of which are shown in Table (4).

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Table 3- Model sensitivity analysis results

Rank	Name	Description	Lower Bound	Upper bound
1	CN2	Soil conservation service run-off curve number for moisture condition II	35	98
2	ESCO	Soil evaporation compensation factor	0	1
3	SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	-0.5	0.5
4	SFTMP	Snowfall temperature (°C)	-5	5
5	SMTMP	Snow melt base temperature (°C)	-5	5
6	EPCO	Plant evaporation compensation factor	0	1
7	ALPHA_BF	Baseflow alpha factor (days)	0	1
8	SLSUBBSN	Average slope length (m)	10	150
9	CH_N2	Manning coefficient for main channel	0	0.3
10	MSK_CO2	Calibration coefficient used to control impact of the storage time constant fro low flow	0	10
11	GW_DELAY	Groundwater delay (days)	0	70
12	RCHRG_DP	Deep aquifer percolation fraction	0	1
13	GWHT	Initial groundwater height (m)	0	25
14	TIMP	Snow pack temperature lag factor	0	1
15	REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)	0	100
16	DEEPST	Initial depth of water in the deep aquifer (mm)	1000	5000
17	SOL_BD	Moist bulk density	-0.4	0.4
18	GWQMN	Treshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	500
19	OV_N	Manning's "n" value for overland flow	0	0.8

Table 4- Values of model performance evaluation indicators in runoff simulation in implemented models

Landuse map		1986	1996	2005
Calibration	YEAR	1982-1989	1991-1998	2000-2005
	R2	0.74	0.9	0.84
	NS	0.74	0.88	0.83
Validation	YEAR	1990	1999	2006
	R2	0.54	0.76	0.81
	NS	0.52	0.61	0.8

Effect of land use change on water balance components of Doroudzan dam basin

In order to reveal the effect of land use change on the hydrological components of the basin, a scenario was defined for each land use map. The scenarios were considered equal to 26 years (1979 to 2006) in terms of climatic data. For each scenario in the SWAT model, a separate simulation was performed, and the simulation results were entered into the SWAT-CUP software as input. Then the parameter values in the best simulation obtained from the first, second, and third periods were set for the first, second and third scenarios, respectively, and were simulated to investigate the effect of land use change. The first scenario was chosen as the control scenario for better comparison; This means that if the land use does not change in the time step of this study, the hydrological components corresponding to the results of the first scenario will remain. The results of the simulation of the defined scenarios are shown as the average for the whole period in Table (5). The three components of surface runoff, percolation, and evapotranspiration for the whole period are shown in Figure (4). According to Table (6), in the second and third scenarios, surface runoff decreased by 27.7% and 13.5%, respectively, compared to the control scenario (Figure 5). In addition, the total runoff of the whole period in the second scenario is less than in the third scenario. Considering the same rainfall conditions in the three scenarios, it can be inferred that land use change has affected the amount of runoff and runoff distribution, in the control scenario, the amount of runoff was more than in the other two scenarios. An increase of 40% and 203% in agricultural lands and gardens has caused a decrease in runoff due to uncontrolled water withdrawal for irrigation of irrigated crops, and as a result, the volume of water leaving the basin has decreased. Also, the evapotranspiration rate of the second and third scenarios compared to the control scenario increased by 19.5% and 18.1%, respectively (Figure 6). This is due to the increase of vegetation, including irrigated lands (gardens and agriculture) in the basin in the second and third scenarios. Also, the study of long-term annual percolation in three scenarios shows that the percolation has changed like surface runoff (Figure 7).

Table 5- Water balance components Three scenarios simulated in millimeters

Water balance components	scenario 1 (control)	scenario 2	scenario 3
Surface runoff	131.43	95.01	113.73
Evapotranspiration	248.6	297	293.7
percolation	79.97	76.38	67.23
Deep aquifer recharge	58.17	39.69	34.93
Curved number	74.81	72.28	74

Table 6- Percentage of water balance components in three simulated scenarios

Water balance components	senario	
	1 and 2	1 and 3
Surface runoff	-27.7	-13.5
Evapotranspiration	19.5	18.1
percolation	-4.5	-15.9
Deep aquifer recharge	-31.8	-40
Curved number	-3.4	-1.1

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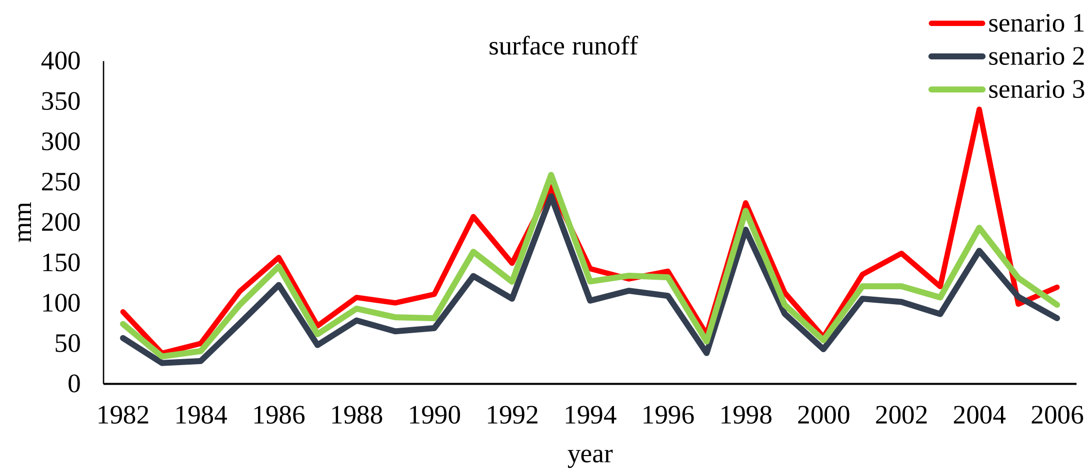

Fig. 5- Total annual surface runoff of three scenarios in millimeters

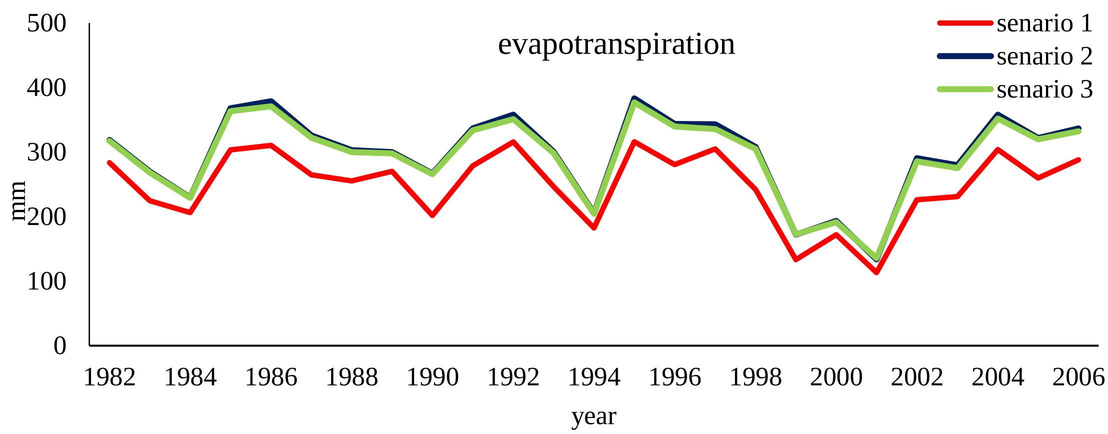

Fig. 6- Total annual evapotranspiration of three scenarios in millimeters

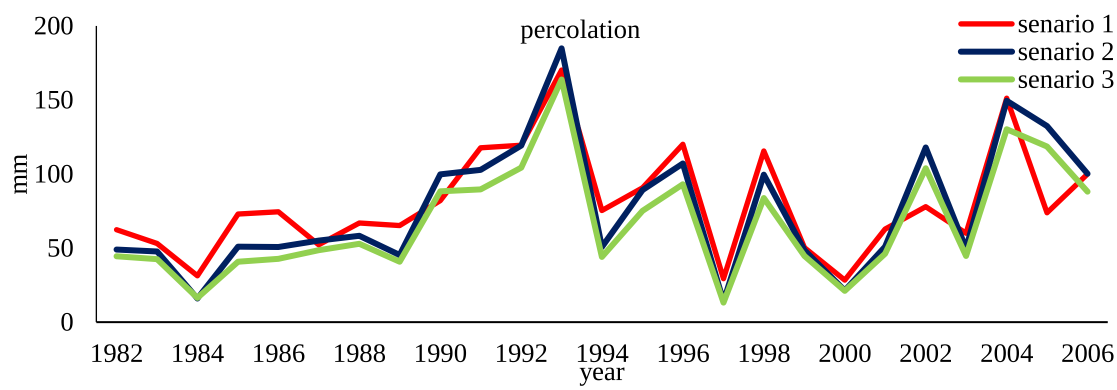

Fig. 7- Total annual percolation in three scenarios in millimeters

Conclusion

Due to the changes made in the basin area and the conversion of many rangelands into agricultural lands and gardens, the expansion of cities and the reduction of forests etc, investigation of these effects on the amount of water balance components in the basin and measuring them using hydrometric station statistics at the basin outlet can show the severity of the damage. In this study, satellite images were used to evaluate the changes in the land use of the basin. After the necessary pre-processing, the images were classified using a supervised method with the maximum probability algorithm to prepare a map of the basin lands. The results showed that in the period from 1986 to 2005, residential areas, agricultural lands and gardens had an increasing trend, which is due to increasing population and villages and increasing human needs, as well as increasing irrigation and rice cultivation in the region. These changes reflect the trend of degradation in the region through the replacement of these land uses with rangelands, barren lands, and forests. To evaluate the effect of land use change on runoff, three SWAT models were implemented using three land use maps, including land use in 1986, land use maps in 1996 and 2005 for the study area. The results of flow simulation in the region were acceptable in all three models, so the coefficient of explanation between the observed and simulated data showed acceptable results. After simulating the SWAT model, three optimal values of the parameters of each period were placed for the defined scenarios. The results showed that with the change in land use, the value of the curved number in the second and third scenarios decreased by 3.4% and 1.1%, respectively, due to the reduction of barren lands and increased vegetation in the region. Annual runoff study in three scenarios shows that under the second and third scenarios, surface runoff decreased by 27.7% and 13.5%, respectively, compared to the control scenario. An increase of 40% and 203% in agricultural lands and gardens has caused a decrease in runoff due to uncontrolled water withdrawal for irrigation of irrigated crops. As a result, the volume of water leaving the basin has decreased. Also, the evapotranspiration rate of the second and third scenarios compared to the control scenario increased by 19.5% and 18.1%, respectively. The reason for this is due to the increase of vegetation, including irrigated lands (gardens and agriculture) in the basin in the second and third scenarios. Considering the influential role of land use changes in reducing the outflow from the basin and other components of water balance, it is suggested that strategies such as irrigation, and optimal change of basin cultivation pattern be investigated.

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