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Simultaneous effects of climate and land use change on watershed hydrological processes

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Abstract: This research aims to investigate simultaneous effects of climate change and land use change on runoff and real and potential evapotranspiration in Mehrgerd Watershed in South Western Iran. To this end, land use maps were produced for years 1987, 2002, and 2017. Then, 2032 map was predicted. Future projections of the Canadian earth system model (CanESM2) model based on representative concentration pathway 8.5 (RCP8.5) emission scenario were used. The projections were downscaled by statistical downscaling model (SDSM) to simulate future climate of the watershed during 2017–2032. Model of soil and water assessment tool (SWAT) was employed to simulate watershed's hydrological processes. R^2 and NSE for calibration were 0.73, 0.69, respectively. The values for validation were 0.71 and 0.58, respectively. The results showed the contribution of climate change to runoff and real and potential evapotranspiration was 76%, 74%, and 90%, respectively. Furthermore, the land use change contribution to the mentioned components was 24%, 26%, and 10%, respectively. Therefore, effects of climate change on runoff and real and potential evapotranspiration was more significant than that of land use change.

Keywords: downscaling; evapotranspiration; Mehrgerd Watershed; runoff; SVM; SWAT.

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1 Introduction

According to the UN report, about One-fifth of the world's population suffers from water shortage (Xu, 2018). Water scarcity is a severe threat to national welfare and sustainable development in arid and semi-arid regions of the world. Such areas face a strong unbalance between water supply and demand (Koundouri and Karousakis, 2006). There are many factors affecting watershed hydrological processes. Two key factors are climate change and land use change (Marhaento et al., 2018). Since around 82% of Iran is located in arid and semi-arid climates, severe droughts are recognised as a normal feature of Iran's climate. By doubling the CO_2 concentration in 2,100, the average temperature in Iran will rise by 1.5°C–4.5°C, which will result in a significant change in water resources (Amiri and Eslamian, 2010). Climate change and land use change affect various water balance components such as base flow, surface runoff, evapotranspiration and etc. Therefore, the probable effects must be considered to predict the water balance changes in the future (Kundu et al., 2017).

Appropriate management of water resources is essential for sustainable developement (Goonetilleke and Vithanage, 2017). In recent decades, hydrological models have been widely used by hydrologists and water resources managers to analyse watershed systems (Jajarmizadeh et al., 2012). The SWAT model is an example of conceptual and physically-based hydrological models that is used to simulate the watershed hydrological processes (Neitsch et al., 2011). Currently, 3D models of atmospheric-ocean general circulation (AOGCM) are the most important tool for producing climate scenarios. However, the coarse spatial resolution of these models is one of their problems. To deal this issue, downscaling models can be applied (Wilby et al., 1998). Therefore, to address this issue, several statistical and dynamic downscaling models have been developed in the last two decades. These models downscale outputs of general circulation models (GCMs) with a high-resolution at the regional scale. SDSM, a statistical downscaling model (SDSM) is widely used around the world (Mahmood and Babel, 2013).

Producing and classification of land use maps by remote sensing techniques is of important in providing the land use changes information. Recently, to this end, various algorithms have been developed (Taati et al., 2015). The support vector machine (SVM) is one of the new methods used to classify satellite images in order to produce land use maps (Kavzoglu and Colkesen, 2009).

Many studies have been done to assess the effects of climate change and land use change on water balance components in different regions around the world. Many studies have been conducted to investigate the effects of climate change on watershed hydrology (Anand and Oinam, 2019; Bhatta et al., 2019; Emami and Koch, 2019; Luo et al., 2017; Sood et al., 2013; Talebi et al., 2019; Zhang et al., 2016a; Zuo et al., 2015). These studies suggest temperature is very likely to increase in future. However, the direction of change in precipitation and river flow is unknown and varies depending on the region of the study as well as the apllied GCMs/RCMs and downscaling models.

Also, many researches investigated the impact of land use change on watershed hydrology. Palamuleni et al. (2011) showed that as a result of the conversion of forests into pastures, fields and residential areas, peak discharge increased, while focus time decreased. Anand et al. (2018) showed that urbanisation presented the greatest effect on rising surface runoff. Evapotranspiration also increased. In recent years, simultaneous effects of climate change and land use change on hydrological processes also have been studied (Kundu et al., 2017; Marhaento et al., 2018; Puno et al., 2019; Woldesenbet et al., 2018; Zhang et al., 2016b).

Mehrgerd Watershed is a mountainous region and snowfall is the dominant form of precipitation in the region. Moreover, Mount Dena is covered with snow all year. Local people believe that recently, the amount and frequency of precipitation in Spring, Summer and Autumn has decreased, remarkably (Saboohi et al., 2018). Water resources of Mehrgerd Watershed present a sustainable situation by the recent decades. Recently, due to changes in land use and climate, the hydrological system of the watershed has changed which resulted in a shortage of available water. Therefore, regarding the importance of land use and climate change effects of different components of the hydrological cycle, the aims of this research are as the following four steps:

1 Forecasting the future land use changes based on the observed trend of recent land use changes by applying the SVM algorithm

2 Projecting the future climate change using the CanESM2 simulations

3 Simulating the hydrological processes of the watershed using SWAT model

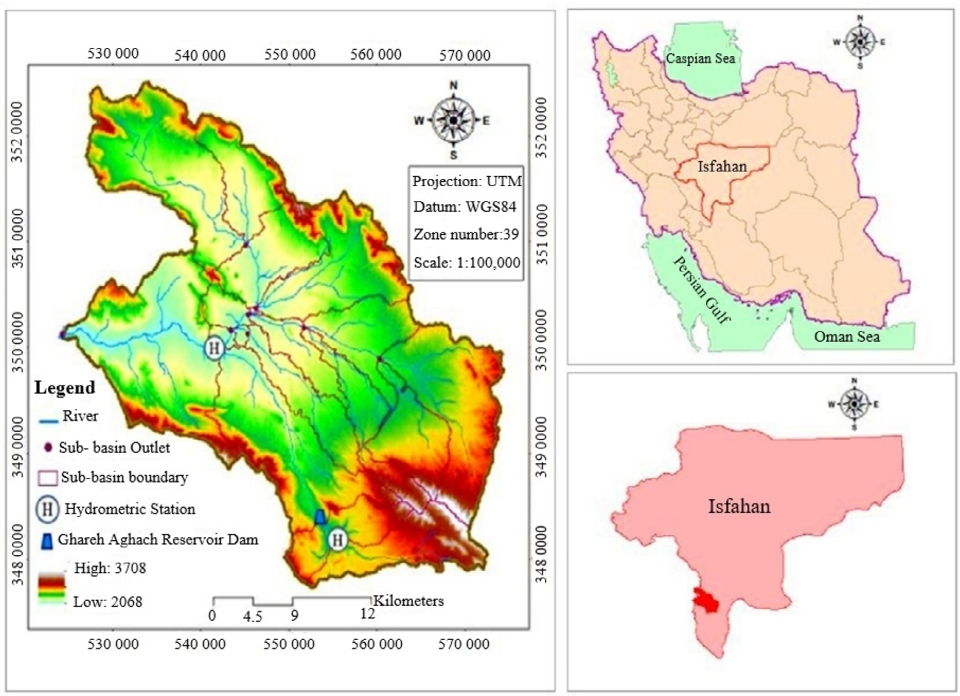
4 Investigation of simultaneous effects of climate change and land use change on runoff and real and potential evapotranspiration.

2 Methodology

2.1 Study area

Mehrgerd Watershed is part of the Karun Catchment with area of 1,275.59 km^2, located in the northern part of the Semirom City of Isfahan Province) Figure 1. The lowest and highest elevations in Mehrgerd Watershed are 2,068 and 3,708 m, respectively. The area of plains and mountains of the watershed is 653.75 and 621.84 km^2, respectively. The annual average of precipitation in the plains is 339 mm. This value for the mountains is 368 mm. The lowest and highest temperatures of the watershed are –23°C and 37°C, respectively.

Figure 1 Geographic location of Mehrgerd Watershed (see online version for colours)



2.2 Land use

In order to investigate land use change impacts on runoff and real and potential evapotranspiration of the region, three satellite images for years 1987, 2002 and 2017 were produced with an almost identical time interval (https://www.usgs.gov). Also, those satellite images were selected that:

1 the effects of cloud and snow cover were minimal

2 plant coverage reached to the maximum growth.

The specifications of the employed satellite images are presented in Table 1. After preparing Landsat satellite images, to eliminate existing errors, the atmospheric and radiometric corrections were performed using the FLAASH method in the ENVI5.3 software environment. For better classification of the categories, the appropriate RGB for each image was determined. Accordingly, the best band combination of sensors (TM) 147, (ETM+) 347, and (OLI) 754 was considered. Then, the training samples for each class were prepared. 70% and 30% of the samples were selected for training and test, respectively. Seven types of land use including agriculture, rain-fed agriculture, garden, rangelands, rocky and bare lands, residential areas and water surfaces were determined and transferred to the ENVI5.3 software. As mentioned before, SVM algorithm was applied to classify satellite images. This method has four kernel types (linear, polynomial, radial, and Sigmoid) (Taati et al., 2015) that all the four kernels were tested to obtain the best result. SVM algorithm is a classification method introduced by Vapnik and Chervonenkis, 1971 and Vapnik, 1999. The algorithm is a nonparametric statistical supervised method (Mountrakis et al., 2011). SVM algorithm is a binary classification model which uses an optimal hyperplane. The model divides training data into two different classes with a maximum margin. The optimal hyperplane and the data that close the width of the margin are called support vectors (Chatterjee et al., 2012).

Table 1 Specifications of satellite images

Sensor type	*Imaging data*	*(Pass/row)*
TM	21.June.1987	164/38
ETM+	5.May.2002	164/38
	14.May.2002	163/38
OLI	22.May.2017	164/38

In order to assess the accuracy of the maps classified, the following equations are applied.

$$P_0 = 1/N\sum Pij \tag{1}$$

where

P_0 total accuracy

N the number of test pixels

$\sum Pij$ the sum of the elements of the original diameter of the error matrix (Foody, 2020).

$$K = \frac{P_0 - P_c}{1 - P_c} \tag{2}$$

where,

Po overall accuracy

Pc the expected agreement.

Therefore, when the overall accuracy closes to 100 and the Kappa coefficient closes to one, classified maps are more accurate. The Kappa coefficient > 0.75 are cited as very good accuracy (Bharatkar and Patel, 2013).

2.3 Climate

To project climatic variables of the region since 2032, the daily data of minimum and maximum temperature of Borujen station and precipitation data of TangeZardaloo station for the period 1984–2005 were used. SDSM model for downscaling the climatic variables was applied. SDSM model is a multivariate regression model for statistical downscaling of climate simulations (Hashmi et al., 2011). Future projections of CanESM2 model under RCP8.5 emission scenario for the period 2017 to 2032 were downscaled. The greenhouse gas emissions and concentrations in RCP8.5 scenario increase considerably over time. Continuance of this trend leads to a radiative forcing of 8.5 W/m^2 by 2100 (Riyahi et al., 2011). So, it was assumed that if the most pessimistic scenario (without any policy to deal with greenhouse gases) be considered, how climate change affects hydrological processes of Mehrgerd Watershed in the near future. In order to assess the efficiency of the model, NS and R^2 were used as the following equations (Moriasi et al., 2012):

$$NS = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{N} (O_i - Pi)^2} \quad (3)$$

$$R^2 = \left[\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2}} \right]^2 \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}} \quad (5)$$

where,

O_i observed value

$\bar{O}$ average of observation value

P_i simulated value,

$\bar{P}$ average of simulated value and n: number of statistical years.

2.4 SWAT model simulation

SWAT is a semi-distributive and continuous model to simulate the quality and quantity of surface and ground water in watersheds and river basins. SWAT uses digital elevation model (DEM) to divide the main basin into a number of sub-basins. This model divides the sub-basins into smaller discrete hydrologic response units (HRUs) with homogenous biophysical attributes. HRU is a combination of land use, soil type, and slope (Neitsch et al., 2011; Puno et al., 2019; Shanka, 2017). To perform SWAT model in the watershed for water balance simulation, soil and land use maps, daily climatic data including rainfall, minimum and maximum temperatures, relative humidity, solar radiation, and wind speed (from meteorological stations) were used. Monthly data of hydrometric stations were also. The applied data are presented in Table 2.

Table 2 Data used in the present study

Data	*Major parameters*	*Time*	*Source*
Climate data	Rainfall, temperature, humidity, solar radiation, sunshine hour	2002–2016	Iran Meteorological Department
Land use	Land use from satellite data	1987, 2002, 2017	USGS
Elevation	ASTERGDEM	NA*	USGS
Soil data	Soil	NA*	world soil map
Gage data	Water discharge data	2002–2016	Regional Water Company of Isfahan
Water transmission pipe	Water discharge data	2008, 2009	(RWC), Isfahan
Reservoir dam	Physical features, water discharge data	2011	(RWC), Isfahan

Note: *Not applicable.

Table 3 The parameters sensitivity analysis results for calibration period 2004 to 2012

Parameter name	*Definition*	*t-stat*	*p-value*	*Optimal value*
V__CN2.mgt	SCS runoff curve number for moisture condition II	1.80	0.07	53.74
V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for 'revap.' to occur (mm).	–2.13	0.03	41.73
V__HRU_SLP.hru	Average slope steepness	2.76	0.01	0.60
r__SOL_AWC(1).sol	Available water capacity of the soil layer (1)	–3.49	0.00	-0.04
r__SOL_AWC(2).sol	Available water capacity of the soil layer (2)	–9.74	0.00	-0.40
V__GWQMN.gw	Treshold depth of water in the shallow aquifer required for return flow to occur (mm)	–4.10	0.00	257.88
V__ESCO.hru	Soil evaporation compensation factor	6.73	0.00	0.81
r__SOL_BD(1).sol	Soil bulk density(1)	8.92	0.00	0.39
r__SOL_BD(2).sol	Soil bulk density(2)	13.77	0.00	0.56
V__PLAPS.sub	Precipitation lapse rate	70.59	0.00	297

2.5 SWAT model calibration and validation

The purpose of model calibration is to optimise the effective parameters. Validation is a performance analysis of the calibrated model for another time period (Abbaspour, 2015). After providing the required information, the water balance of the Mehrgerd Watershed was simulated using the SWAT model during the period 2002 to 2016. Two years warm-up period of the model were considered. To calibrate and validate the SWAT model, SWAT-CUP 2012 was applied. Periods 2004–2012 and 2013–2016 were considered for calibration and validation, respectively. For this purpose, Tange Zardaloo hydrometric station, located near the watershed outlet, was selected. To calibrate the model, 19 parameters were selected. Then, 10 parameters as the most effective parameters were selected to import into the model (Table 3). The SUFI_2 algorithm was employed for this purpose. SUFI_2 algorithm is an inverse optimisation method in which all uncertainty sources in the introduced domain for each parameter are taken into account. In this method, the initial range of parameters is replaced by a wide range of new parameters. This process continues until the P-Factor closes to one and the R-Factor closes to zero (Uniyal et al., 2015).

2.6 Perform scenarios

The effect of climate change and land use change on runoff and real and potential evapotranspiration parameters was investigated based on two scenarios. The two applied scenarios are as follows: Scenario I, run the SWAT model with future climate data and baseline period land use data; scenario II, run the SWAT model with the baseline period climate data and future land use data. Then, the contribution of any of the two factors, climate change and land use change, on the mentioned parameters was determined.

3 Results and discussion

3.1 Predicting future land use change

Land use maps for years 1987, 2002, and 2017 were produced using ENVI5.3. Then, the maps were classified by SVM algorithm. The best results were obtained using the polynomial kernel. Finally, the land use map for year 2032 was predicted based on area changes of the classes over time (Figure 2).

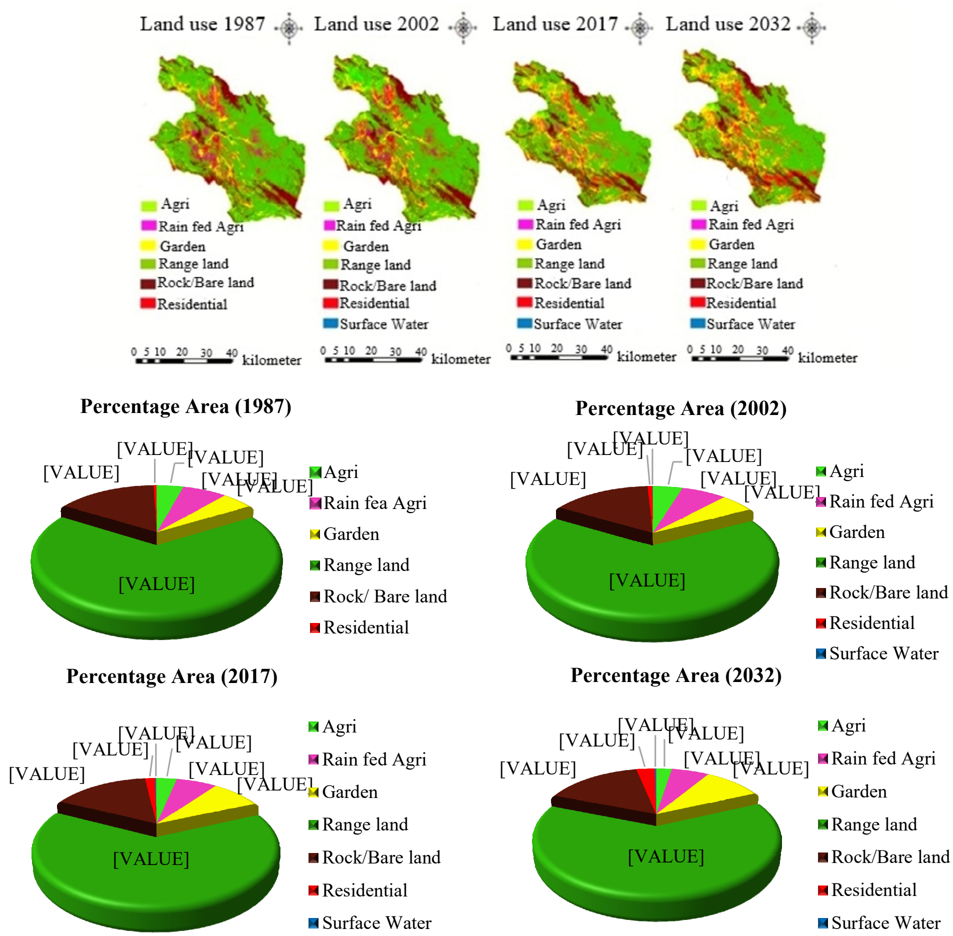
Accuracy of the produced maps is presented in Table 4. The results show that the prepared maps present acceptable accuracy. Accordingly, the land use map for 2032 was predicted.

Table 4 Accuracy of the produced maps for 1987, 2002, and 2017

Year	*Overall accuracy (%)*	*Kappa*
1987	82.23	0.8
2002	75.45	0.7
2017	95.11	0.9

The results presented by Figure 2 show that the area of agricultural lands increased by 11.03% in 2002 compared to 1987. The reason of agricultural lands growing in 2002 is rising the precipitation. The area decreased by 29.39% in 2017 compared to 2002. It is forecasted agricultural land use will reduce by 24.55% in 2032 in comparison to 2017. The results illustrate that rain fed agriculture increased by 1.56% in 2002 compared to 1987 and then decreased by 7.96% in 2017. Finally, it will decrease for 8.04% in 2032. For garden, the results show that this land use increased for all three time periods. For rangeland, the results show that this land use type decreased during all three periods. So rangeland decreased in the years 1987 to 2002, 2002 to 2017 and 2017 to 2032 for 2.09%, 2.89%, and 1.90%, respectively. The main reasons of the rangelands degradation in this region are early entry of nomads, overgrazing of livestock, imbalance between the number of livestock and pasture capacity, and precipitation reduction (Saboohi et al., 2018). The results also present that areal extension of rocky and bare lands shows no significant change during the chosen years. The results show that the residential areas presents a rising trend during the four years.

Figure 2 Land use maps and area of the classes during 1987, 2002, 2017, and 2032 (see online version for colours)



3.2 *Future climate simulation using SDSM model*

To project future climate, SDSM5.2 model was applied. The best variables were selected for the downscaling of temperature and precipitation. The selected variables are presented in Table 5. Model performance was assessed using statistical criteria. The results are shown in Table 6. Mean and standard deviation of observed and simulated precipitation and minimum and maximum temperatures are compared and indicated in Figure 3.

Table 5 List of predictor variables used for statistical downscaling of minimum and maximum temperatures and precipitation

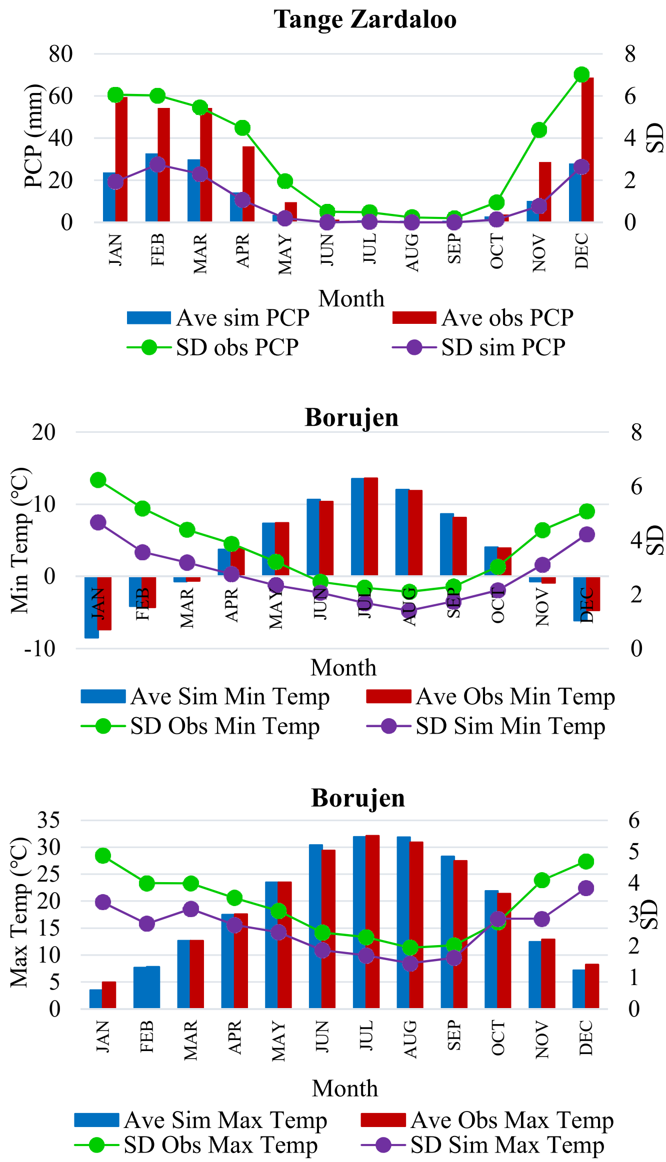
Parameter	*Predictor variable*	*Abbreviation*	*p-value*	*Partial correlation*
Precipitation	ncepmslpgl.dat	Mslp	0.01	0.1
	ncepp1_vgl.dat	p-v	0.02	0.08
	ncepp8_ugl.dat	p8-u	0.01	0.1
	ncepp8zhgl.dat	p8zh	0.3	0.04
	nceps500gl.dat	p500	0.2	0.09
Min temperature	ncepp5_ugl.dat	p5_u	0.03	0.4
	nceps500gl.dat	p500	0.15	0.2
	ncepp5thgl.dat	P5th	0.3	0.18
	ncepp5zhgl.dat	P5zh	0.006	0.5
	ncepp8_ugl.dat	p8-u	0.00	0.16
	nceptempgl.dat	Temp	0.21	0.2
Max temperature	ncepmslpgl.dat	Mslp	0.00	0.3
	ncepp5_ugl.dat	p5_u	0.02	0.04
	nceps500gl.dat	p500	0.13	0.2
	ncepp8_vgl.dat	p8-v	0.5	0.4
	ncepshumgl.dat	shum	0.04	0.03
	nceptempgl.dat	temp	0.5	0.1

Table 6 Performance analysis of CanESM2 model (see online version for colours)

Evaluation index	*Precipitation*	*Min temperature*	*Max temperature*
R2	0.92	0.99	0.99
RMSE	5.81	0.16	0.21
NASH	0.39	0.99	0.99

The results show that simulated temperatures present more correlation with observations compared with simulated precipitation. The results obtained by Sarwar et al. (2010) support these findings. The reason is that the temperature is a continuous variable that is less affected by the time anomalies. The average of simulated precipitation in the future will be considerably smaller than the average of observed precipitation. Also, the highest standard deviation difference between observed and simulated precipitation was on January and December by 4.14 and 4.37, respectively. That means standard deviation of the observations is larger than that of simulations. In case of temperature, in some months, especially in January and December for minimum temperature and January and November for maximum temperature, there is a relatively small difference between the standard deviation of the simulations and observations. It can be claimed simulations of minimum and maximum temperatures match the observations acceptably. The downscaling results of CanESM2 model in this region are presented in Figure 3. The results exhibit a decrease in precipitation and a rising in temperature. Saboohi et al. (2018) and Zamani Nouri et al. (2014) support these findings.

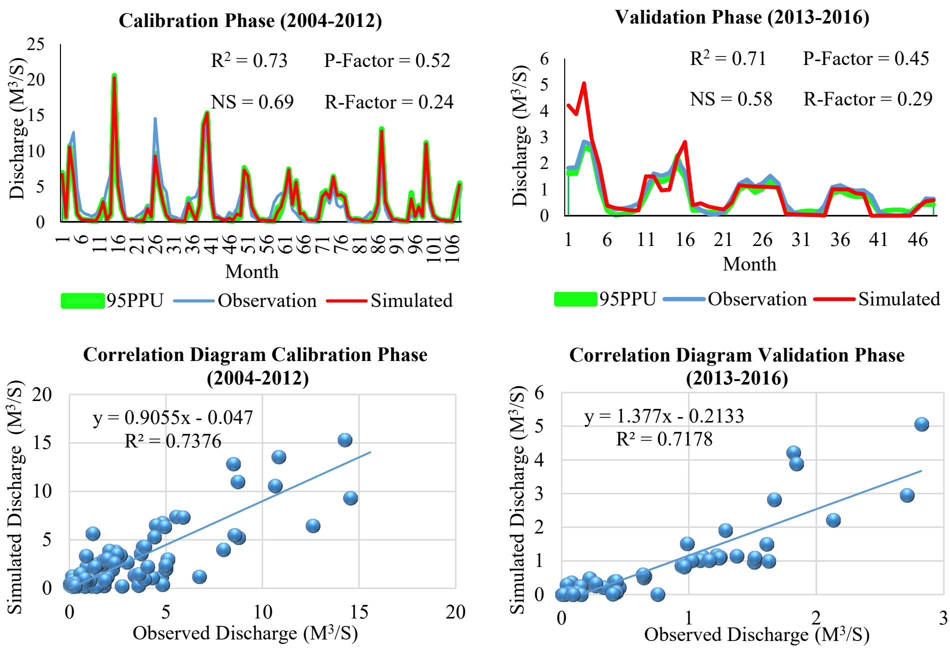
Figure 3 Comparison of mean and standard deviation of observed and simulated precipitation and minimum and maximum temperatures (see online version for colours)



3.3 *Simulation of hydrological processes using SWAT model*

SWAT model was implemented for the period 2002–2016. Two years were considered for model warm-up. Calibration and validation were performed using SUFI-2 algorithm. Periods 2004–2012 and 2013–2016 were chosen as calibration and validation periods, respectively. R2, NS, P-Factor and R-Factor for calibration period were 0.73, 0.69, 0.52, and 0.24, respectively. For validation period, they were 0.71, 0.58, 0.45, and 0.29, respectively. Based on the P-Factor and R-Factor results, an acceptable percentage of observed data were in the 95% uncertainty band. Runoff simulations based on a SUFI-2 algorithm are exhibited in Figure 4. The results of R2 and NS for both the calibration and validation periods indicate that simulation of the monthly runoff was satisfactory. By comparing the simulated and observed hydrographs, it is clear that in some months during the calibration period (e.g., May 2004 and March 2006) as well as validation period (e.g., May 2013, March 2014, April 2015, and March 2016) at peaks, correlation is smaller. Similar results was reported by Chu and Shirmohammadi (2004) and Tolson and Shoemaker (2004). That is probably because the watershed is mountainous and also the existence of calcareous and cretaceous calcareous dolomites which constitute the major part of the mountains.

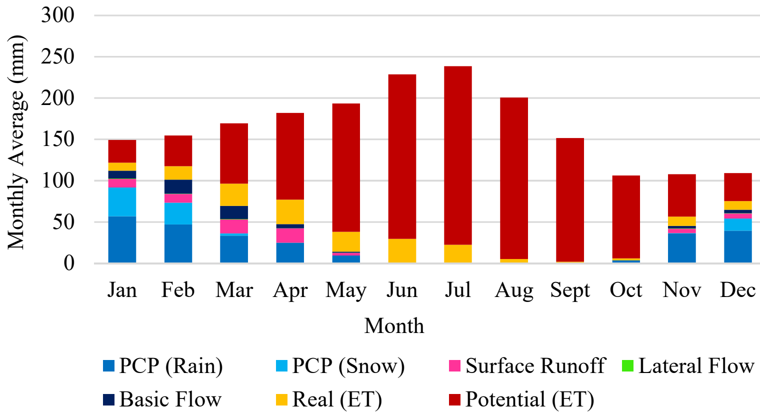
Figure 4 Runoff simulations using a SUFI-2 algorithm (see online version for colours)



3.4 *Water balance components of the watershed*

All water balance components, e.g., precipitation, snowmelt, surface runoff, permeability, evapotranspiration, deep water permeation, subsurface flow, and groundwater flow were simulated using SWAT model. The monthly average of watershed water during 2004 to 2016 is presented in Figure 5. The average precipitation of Mehrgerd Watershed is 305.6 mm. About 64% of precipitation evaporates by atmosphere through evapotranspiration process. Approximately, 31% directly flows into the drainage network as the surface runoff, lateral flow and return flow. From 6% of the water penetrated to soil layers, about its 1% infiltrates to groundwater aquifers, providing base flow of the river.

Figure 5 Monthly average of the watershed water balance (2004–2016) (see online version for colours)



3.5 The Scenario I: Implementation of the SWAT model with future climate and baseline period land use data

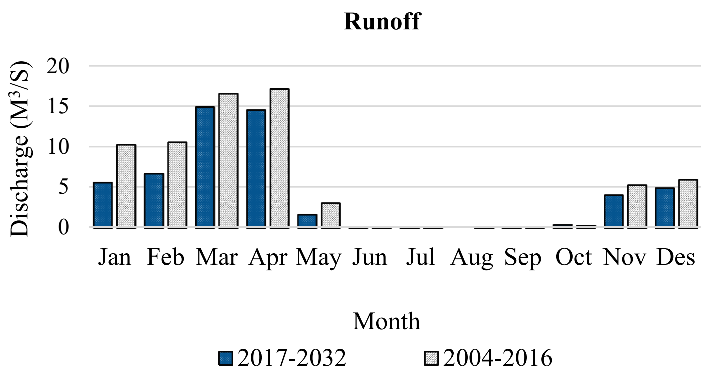
3.5.1 Effects of climate change on runoff

Analysis of SDSM outputs for the period 2017–2032 indicates precipitation reduction and temperature rising for all months in compare to the baseline period. The results also show a decrease in the long-term annual runoff for 23.82%. Figure 6 illustrates monthly changes in water balance components under a changing climate. Figure 6(a) shows peaks of runoff are moved from April to March. In the past, the dominant type of precipitation in the Winter was snow. Therefore, regarding the past temperature patterns, the maximum runoff occurred in early Spring (with late Winter and Spring snow melting and Spring rainfall). In the near future, precipitation amount will reduce compared to the past. However, due to the changes in precipitation regime, the runoff peak will be moved from early Spring to late Winter. Similar results were obtained by Abraham et al. (2018), Emami and Koch (2019) and Sood et al. (2013).

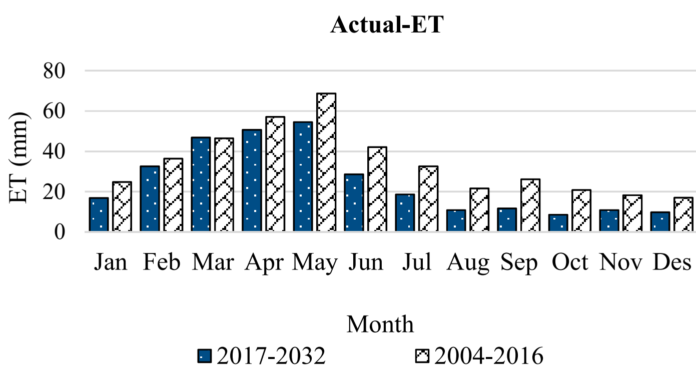
3.5.2 Impact of climate change on real and potential evapotranspiration

The results indicate that average of annual real evapotranspiration will decrease in the future (2017–2032) for 26.03%. This is resulted by the future decrease in precipitation and subsequent lack of available water to be evaporated by the atmosphere (Figure 6(b)). Due to the close relationship between potential evapotranspiration and temperature, therefore, annual potential evapotranspiration will rise 10.20% (Figure 6(c)). So, maximum potential evapotranspiration in the watershed will be in Summer. Thompson et al. (2014) supports the results and reported an increase in evapotranspiration simulated by all applied models due to temperature rising. Mundo-Molina (2015) showed that by changing the temperature from 0.1°C to 0.45°C, evapotranspiration will increase from 2% at present to 7% in 2032. Nistor et al. (2016) investigated the effect of climate change on evapotranspiration in the Carpathian region from 1961 to 2010. The results showed a temperature increase results in evapotranspiration rising.

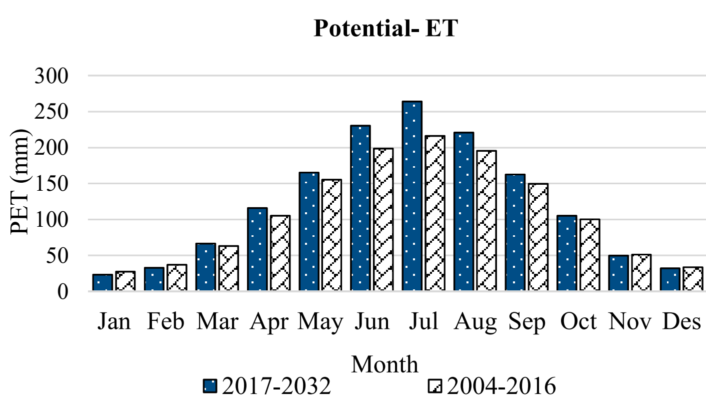
Figure 6 (a) Runoff, (b) real ET, (c) potential ET under effects of climate change (2004–2016, 2017–2032) (see online version for colours)



(a)



(b)



(c)

3.6 Scenario II: Implementation of the SWAT model with baseline period climate and future land use

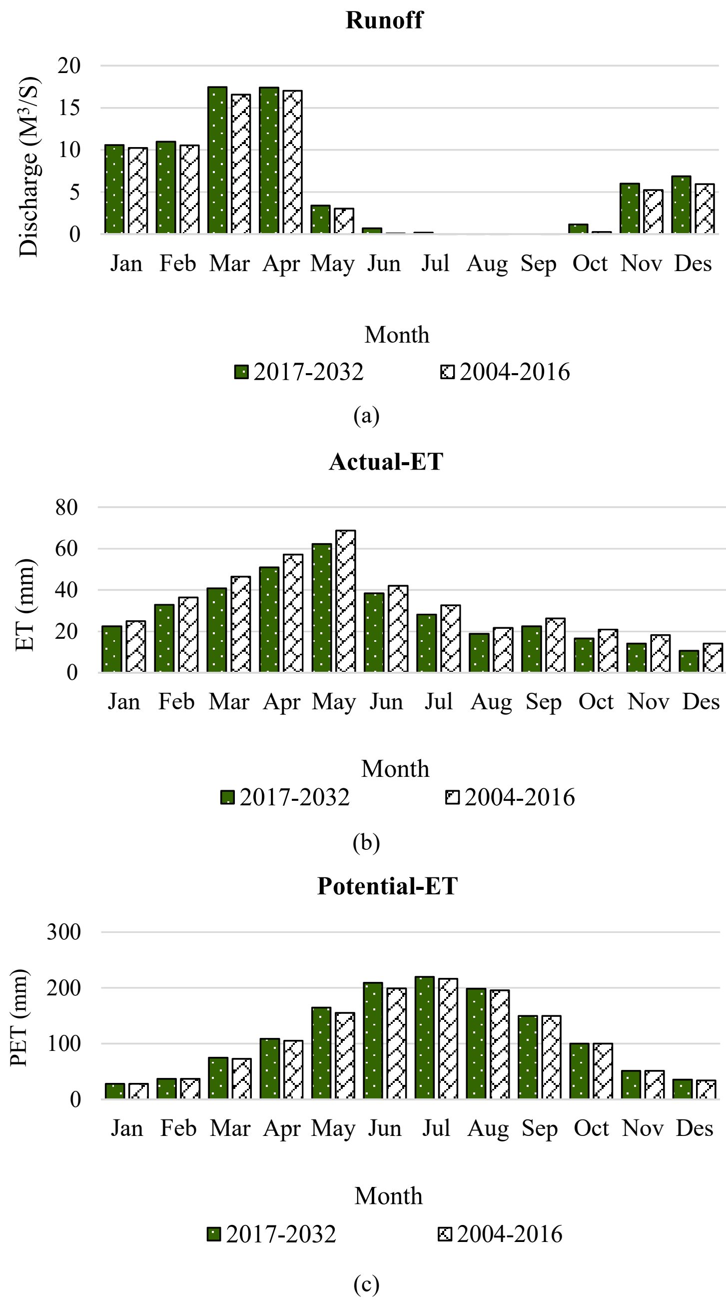
3.6.1 Investigating the impact of land use change on runoff

Monthly changes in water balance components under the impacts of land use change are presented in Figure 7. Figure 7(a) shows an increase of 8.09% in annual runoff due to land use change. In this region, the freezing season begins in late Autumn and continues until late Winter. Runoff is produced by melting snow caused by the gradual warming in the early Spring. Beginning the season of plants growth in April and its continuance to May and June, led to a decrease in runoff (compared to early spring). Reducing the areal extension of Rangelands and rising that of residential areas, result in impermeable surfaces rising. This will lead to runoff increase for the future in compare to the baseline period. Similar results were obtained by Baker and Miller (2013) in the East African catchment, reporting surface runoff increased due to land use change. Narsimlu et al. (2013) investigated the effect of climate change on water resources of the Upper Sind river basin using SWAT. The results showed annual flow average increased by 4.16% for the second half of year. Zare et al. (2016) investigated the effect of land use change on runoff in north of Iran. The results showed that runoff in all scenarios is increased by 45% due to changes in land use. Increasing the urbanisation and deforestation was one of the most important factors in runoff rising.

3.6.2 Investigating the impact of land use change on real and potential evapotranspiration

Figure 7(b) shows a 12.38% reduction in annual real evapotranspiration in the future. Because of higher temperature and more available moisture to be evaporated, maximum real evapotranspiration is in April and May. The lowest amount is in November and December. In January, February, and March, despite high precipitation and available moisture, due to the low temperature and lack of vegetation cover, real evapotranspiration is low. Considering the rangeland changes in the future, evapotranspiration from the soil surface will decrease. Wang et al. (2008) reported supporting results, investigating the effect of land use change on hydrological processes of watersheds in China. The results showed that the decrease in forests caused an increase in annual runoff, decrease in groundwater due to a decrease in soil permeability, and a decrease in evapotranspiration. Kundu et al. (2018) investigated the effects of land use change and climate change on real evapotranspiration in the Narmada river basin of Central India. The results showed that real evapotranspiration will decrease due to climate and land use change in the future. The results also indicated annual potential evapotranspiration increased by 2.1% compared to the baseline period. Vegetation cover degradation especially rangelands causes an increase in surface temperature of the earth. Therefore, potential evapotranspiration rises by vegetation reducing and a gradual temperature rising. In Mehrgerd Watershed, growth period of plants starts early April. Considering the land use change and vegetation cover reduction especially in rangelands, it is expected that potential evapotranspiration will increase during the period of growth. Therefore, potential evapotranspiration will rise in Spring and Summer compared to the baseline period (Figure 7(c)).

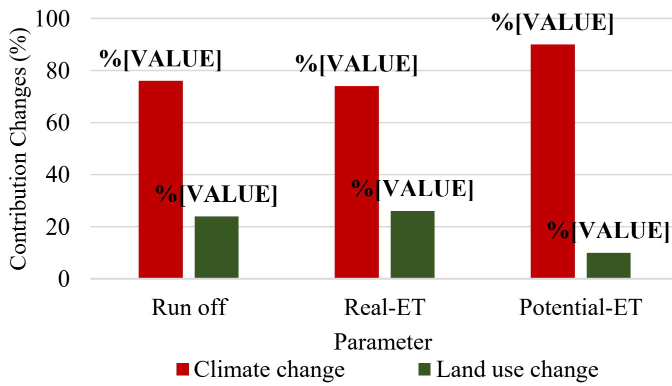
Figure 7 (a) Runoff, (b) real ET, (c) potential ET under effects of land use change (2004–2016, 2017–2032) (see online version for colours)



3.7 *Investigating the separate contribution of climate change and land use change*

Impact of climate change and land use change on runoff and real and potential evapotranspiration are compared in Figure 9. As the figure shows, the contribution of climate change to changes in the runoff, real and potential evapotranspiration is 76%, 74%, and 90%, respectively. Contribution of land use change to the changes in mentioned components is 24%, 26%, and 10%, respectively.

Figure 8 Contribution of climate change and land use change to changes in runoff and real and potential evapotranspiration (see online version for colours)



4 Conclusions

In this study, the effects of climate change and land use change on runoff and actual and potential evapotranspiration in Mehrgerd Watershed were analysed. The land use maps were produced by SVM algorithm and polynomial kernel. Then, land use changes were predicted for 2032. The results presented agricultural land, rain fed agricultural land, and rangelands will decrease. Rocky and bare lands, gardens, residential areas, and water surfaces will increase. Climate variables for 2032 were projected using CanESM2 model simulations based on RCP8.5 scenario. Then, the outputs were downscaled by SDSM. The results showed 53.48% reduction in precipitation and 0.84°C and 3.99°C rising in minimum and maximum temperatures, respectively. SDSM model simulated precipitation with larger error compared with minimum and maximum temperatures. Temperature is a continuous parameter and is less affected by temporal anomalies. However, precipitation is a discrete parameter and is affected by various factors. It should also be in consideration that SDSM is a regression model. Water balance components were simulated by the SWAT model. In Mehrgerd Watershed, the contribution of evapotranspiration to water losses is larger than that of the other components of water balance.

SWAT classifies precipitation into rain and snow using daily temperature. In case of runoff simulation during the months after the cold season, it can be concluded that the model was not enough efficient to simulate snowmelt in some months. Therefore, the simulated maximum flow presents less match with the observed amounts. Temperature rising and precipitation reducing in the future cause 23.82% runoff decrease and 26.03% real evapotranspiration reduction. Moreover, the increase in temperature causes decrease in available water and 10.20% potential evapotranspiration rising. Degradation of rangelands and increase of residential areas causes 8.09% increase in runoff, decrease of 12.38% in real evapotranspiration and 2.1% growing in potential evapotranspiration. Finally, the results showed that the contribution of climate change to runoff, real and potential evapotranspiration is 76%, 74%, and 90%, respectively. The Contribution of land use change to these components is 24%, 26%, and 10%, respectively. By comparing the impacts of climate change and land use change on any of the mentioned parameters, it was found that the effect of climate change on runoff and real and potential evapotranspiration was more remarkable than that of land use change.

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