Assessment of impacts of change in land use and climatic variables on runoff in Tajan River Basin
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ABSTRACT

The main objective of the present study was to investigate runoff response to climate variables as well as landuse change over the past 30 years in Tajan River Basin, using the SWAT model. After the model calibration, four different scenarios were simulated and compared. Comparison of simulated runoff results determined from different scenarios indicated that climatic variables reduced the amount of runoff while the landuse change increased this amount in most months of the year. Simulated runoff under three landuse scenarios in all months demonstrated that the runoff achieved from scenario 1 was smaller than scenarios 2 and 4. In scenario 4, the runoff amount increased by 3–21% and 0.8–13% in Kordkheil station compared to those of scenario 1 and scenario 2, respectively. Furthermore, the increase in runoff for scenario 4 is 3–19% and 2–12% in Rig Cheshmeh station relative to those of scenario 1 and scenario 2, respectively. Nonetheless, the maximum change in runoff was only 6% under climatic variables. Hence, landuse had more significant impacts on the runoff compared to climatic variables.

Key words | Arc SWAT, hydrological change, remote sensing, Tajan watershed

HIGHLIGHTS

- The main objective is to investigate runoff response to climate variables and landuse change of the Tajan River Basin of Iran.
- Landuse had more significant impacts on the runoff compared to climatic variables.

INTRODUCTION

In a natural ecosystem, a set of human and natural factors such as climate change could cause substantial impacts on the hydrology of basins, including alterations in outflow regime and hydrologic balance of a basin, total runoff volume, and water quality (Wang et al. 2013a, 2013b). In recent years, identification of climate change processes (particularly precipitation) has been widely considered by researchers in the area of hydrology and atmospheric sciences (Pumo et al. 2017). The trend in hydrometeorological series could be induced by natural impacts such as drought and/or human activities. This trend occurrence is quite common in climatic factors of any area; however, its existence in subsequent years could undergo more significant impacts on productive, economic and social components (Malekian & Kazemzadeh 2016). In Iran, due to its warming and severe variations in precipitation along with industrial and agricultural development over the past decade, more attention has to be paid to better acknowledge these two factors on water resources. Tabari et al. (2008) investigated variables of temperature, precipitation, relative humidity, wind speed, and evapotranspiration of a reference plant in two cold and hot climates of Iran via Mann–Kendall method in a 40-year period process. Their findings showed that the highest fluctuations occurred in wind speed and precipitation data series, while the lowest ones were associated with temperature data series. Maryanaji et al. (2008)
concluded that there was a meaningful increasing trend in temperature and decreasing trend in precipitation and annual streamflow in Yalfan River Basin of Iran using the Mann–Kendall test. Moreover, Pirnia et al. (2015) investigated temperature and precipitation variations on the southern coast of the Caspian Sea and concluded that the average regional temperature and precipitation reduced and increased, respectively, in their selected stations. Khoshravesh et al. (2017) examined the trend of precipitation in Mazandaran Province, situated in northern Iran, via Mann–Kendall test during a 30-year period. The results showed that the trends were different in different months/seasons and locations. For instance, there was a declining trend during cold seasons and increasing trend during hot/summer seasons. Moreover, the trend in eastern Mazandaran was often downward, while there was often an upward trend in the west of the province. The average annual precipitation trends are decreasing in this area, affecting mostly the east of Mazandaran where Tajan and Nekarood are situated. Azizi et al. (2008) conducted a climate change study on the southern coasts of the Caspian Sea. The results demonstrated that at most stations minimum temperature showed a positive trend while maximum temperature represented a negative trend. In addition, the range of temperature fluctuation decreased during the whole period and the percentage change in winter and summer was higher than in spring and autumn. Jafari (2008) showed that the climate of the forest areas within Caspian regions has become warmer over the past half century. The results showed that with increasing temperature, the environment would improve to grow trees that grow in very wet soils. However, forests that are on the sidelines may be deteriorated by inappropriate environmental conditions due to climate change. Furthermore, forests that are currently under the pressure of environmental stresses, such as high density, pests, disease, and unfavorable atmospheric conditions, may not be able to withstand additional stresses induced by the climate change. Drought/water limitation is one of the most important climatic factors in Iran, so that almost 50% of the country could be divided into arid and semi-arid regions. Distribution of precipitation amount in most regions is somewhat inappropriate for many plants to grow. These ecosystems are currently under severe pressure due to human activities and climate change conditions, and many semi-arid regions have already been showing early signs of climate change.

Another element that could cause trends in hydro meteorological series is land use change. This change occurs naturally and gradually, but sometimes human activities accelerate the process (Osei et al. 2019). The estimate of forest cover change in natural forests of developing countries was an annual loss of 13.7 million hectares between 1990 and 1995 (FAO 1997). At present, increasing landuse change is one of the most significant issues in Iran. Investigation of landuse status between 1988 and 2004 in the northern forests of Iran demonstrated that 12,152 hectares of forest were deteriorated during this period (Khaledian et al. 2012). Hyrcanian forests have a long history (Jurassic period) and are among the most valuable forests in the world. Mirakhorlou & Akhavan (2017) reported that the Hyrcanian forests in Mazandaran, Golestan and Gilan provinces in Iran have been destroyed by 69, 49 and 21 percent, respectively. Another study reported that the percentage of landuse change in Iran has increased since the past 50 years and is expected to increase in the future (Rajaei et al. 2018). In accordance with the studies conducted in Iran, a substantial decline in forest areas during the period 1958–1994 was chiefly due to forest degradation and agricultural development. Due to these remarkable impacts, landuse change has been identified as a crucial issue in environmental management, landuse planning and its impact on hydrological processes.

A proper understanding of the hydrology under the impacts of historical land use change along with climatic variables requires special modeling. Soil and Water Assessment Tool (SWAT) model has unique features such as simultaneous simulation of interactions between hydrological variables, agricultural management in complex basins with different soils and land use, and its relationship with dynamic change in land and climate change at watershed scale. The SWAT model has been adopted in many basins throughout the world to study climatic variables processes and the impact of landuse change on the hydrological trends (Chang et al. 2016; Yan et al. 2018; Bhatta et al. 2019; Eini et al. 2019; Hajhosseini et al. 2019; Lv et al. 2019; Teklay et al. 2019; Delavar et al. 2020; Zhang et al. 2020; Zolfagharpour & Saghaian 2020).

Regarding the significance of this issue, it is worth mentioning that there have been frequent destructive floods
within the Caspian Sea Basin such as the flood in 2012 in Nekarood River, which caused prominent physical and financial damages. Tajan River Basin is located in the Caspian Sea Basin and is considered to be one of the most damage prone basins of the area. In recent years, the basin has become more susceptible to damages largely due to land-use changes and has always been exposed to the destruction of its natural resources and their conversion to agricultural and residential lands (Farajzadeh and Falah 2008). Therefore, the main objective of this study is to investigate runoff response to change in climatic variables and landuse using SWAT in Tajan River Basin during the past 30 years.

MATERIALS AND METHODOLOGY

Study area

Tajan River Basin, with an area of 3,910 Km², is surrounded by the Alborz mountain range in the south and the Caspian Sea in the north (Figure 1). The basin possesses Hyrcanian forests covering 80 species of trees and shrubs with high biodiversity (Mohammadi & Shataee 2010). Tajan River Basin lies at 53° 4’ 57” to 53° 18’ 26” longitude and 36° 9’ 17” to 36° 26’ 49” latitude. The basin is situated mostly in Mazandaran Province and partly in Semnan Province. Figure 1 shows the location of Tajan River Basin in Iran. The highest point in the Tajan River Basin is located in the south-east, with an altitude of 3,670 m, while the lowest point is situated at its outlet with an altitude of 26 m. The basin covers four cities and 349 villages. Furthermore, the protected areas Dodangeh, Chardangeh, and Boula National Park are within the basin, representing the importance of preserving natural habitats within the basin. The study area, with an average annual temperature of 15 °C (Masoudiyan et al. 2010), enjoys a mild and humid climate. Moreover, the average annual precipitation in the basin is 834 mm. Tajan River Basin is covered with forests and rangelands in the mountainous regions and encompasses agricultural lands in its plains regions. The basin

Figure 1 | The Tajan basin with digital elevation model, river network, and hygrometry stations.
joins the Caspian Sea, the Earth’s largest inland body of water.

**Landuse change analysis**

The images were acquired from Landsat 5, 7, and 5 for the years 1984, 2001, and 2010. These images were edited for geometric and atmospheric correction. The geometric correction was performed based on control points and topographic maps. The atmospheric correction was executed using dark-object subtraction. The satellite images were categorized using the maximum likelihood algorithm. Six land types were identified in the region including forest, agricultural, urban, rangeland, bare land, and water resources. The accuracy of land cover maps was evaluated using the error analysis matrix. The Kappa coefficient was calculated for three periods of landuse. For the 1984 image, RGB colors were used for the Kappa (areas not previously selected for educational samples). For images associated with the recent years, Google Earth was adopted to sample accuracy investigation of the predictions. The Kappa coefficient in land cover maps of 1984, 2001, and 2010 was 81, 83, and 87%, respectively (Congalton 1991; Rajaei et al. 2017).

**Introduction to SWAT and required data**

SWAT is a physically-based, semi-distributed and continuous model used for simulation of hydrological processes in the basin scale. In this model, the basin is split into units of hydrological response based on soil type, landuse and slope classes, enabling the model to perform simulation on a high spatial scale. In order to prepare, calibrate and validate the model, the FAO soil map (FAO 2005) and land use map achieved from Landsat images (Figure 2) were used. The study area was classified using a digital elevation model with a spatial accuracy of 90 m and the weather information (daily precipitation, maximum and minimum temperature) was obtained from the Meteorological Organization of Iran as well as Iran Water Resource

![Figure 2](http://iwaponline.com/ws/article-pdf/20/7/2779/788190/ws020072779.pdf)
Management Company for the 20 stations located in the study area with different time periods (1964–2014). Additionally, monthly streamflow data series of two selected hydrometric stations were provided by Iran Water Resources Management Company. To define the sub-basin, the threshold of 4,000 hectares was selected and the basin and sub-basin boundaries were determined. Given the river network and topography, the area was classified into 27 sub-basins.

407 HRUs were adopted in this study to define the spatial land use change and land management. Thus, we determined different aspects of the agricultural management in the basin such as cropping pattern and irrigation planning. In this study, despite most applications of the SWAT which uses auto irrigation (Faramarzi et al. 2010), we provided the real world irrigation schedule/source for each sub-basin.

The SWAT takes advantage of a simplified version of the EPIC1 model (Williams & Ayars 2005) to simulate the crop growth/yield. The actual daily evapotranspiration (ETact) is simulated using the ETp approach and the daily Leaf Area Index (LAI). In this regard, the planting and harvesting dates associated with the major crops of the model were determined. Then, the parameters affecting the crop yield, LAI and ETact were adjusted. Finally, the crop yield, LAI and ETact were calibrated and simulated. The SUFI-2 algorithm of the SWAT-CUP program was used to perform optimization of the parameters and uncertainty analysis of the SWAT model (Abbaspour & Yang 2015). In this algorithm, the uncertainty is calculated for all effective elements such as rainfall, conceptual model, and estimated parameters. This program takes advantage of the p-value to express to what extent each of the parameters causes uncertainty (percentage of data causing uncertainty at the 95% level of significance). Moreover, R-factor is another parameter associated with uncertainty analysis in the SUFI-2. R-factor indicates the average 95% level of significance determined by the division of standard deviation of simulated data by that of the observed data. The uncertainties were calculated by 2.5th (XL) and 97.5th (XU) percentiles of the cumulative distribution of every simulated point. The goodness of fit is assessed by the uncertainty measures calculated from the percentage of measured data bracketed by the 95PPU band, and the average distance \( r \) between the upper and the lower 95PPU (or the degree of uncertainty) determined from:

\[
r_x = \frac{1}{R} \sum_{i=1}^{k} (X_{U,i} - X_{L,i}), \quad r_{factor} = \frac{r}{\sigma_x}
\]

where \( k \) is the number of observed data points, \( \sigma \) is the standard deviation of the measured variable \( X \).

Table 1 lists the required periods to execute model calibration and validation related to Kordkheil and Rig Cheshme stations. Nash-Sutcliffe and \( R^2 \) were used to evaluate the performance of the model (Abbaspour 2015):

\[
R^2 = \frac{\sum_i (Q_{m,i} - Q_{m})(Q_{s,i} - Q_s)^2}{\sum_i (Q_{m,i} - Q_m)^2 \sum_i (Q_{s,i} - Q_s)^2}
\]

\[
NS = 1 - \frac{\sum_i (Q_{m,i} - Q_s)^2}{\sum_i (Q_{m,i} - Q_m)^2}
\]

Coefficient of determination \( R^2 \) and Nash-Sutcliffe (NS) where \( Q \) is a variable (discharge), and \( m \) and \( s \) stand for measures and simulated respectively, \( i \) is the \( i \) th measured or simulated data and the bar stands for average. Model simulation is considered satisfactory if \( NSE > 0.50 \) and \( R^2 \geq 0.6 \) (Santhi et al. 2001; Moriasi et al. 2007).

Scenario analysis

The impacts of climatic variables and landuse change on hydrology were assessed using the ‘one factor at a time’ strategy based on the calibrated SWAT model. Meteorological data were determined as 1984–1997 and 1997–2014 periods (the year 1997 was the break point in the data). The landuse maps of the years 1984, 2001, and 2010 were adopted to depict the landuse patterns of the two time periods.

Table 1 | Landuse change in area of Tajan River Basin during 1984–2010

<table>
<thead>
<tr>
<th>Year</th>
<th>Forest (ha)</th>
<th>Agriculture (ha)</th>
<th>Pasture (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use 1984</td>
<td>286,747.65</td>
<td>90,918.72</td>
<td>75,821.31</td>
</tr>
<tr>
<td>Land use 2001</td>
<td>230,801.85</td>
<td>114,897.96</td>
<td>103,791.42</td>
</tr>
<tr>
<td>Land use 2010</td>
<td>218,983.23</td>
<td>123,145.11</td>
<td>107,235.81</td>
</tr>
</tbody>
</table>
landuse map associated with the year 1984 was contemplated as ‘base period’ without much human interference/impact, while the maps of the years 2001 and 2010 were considered as ‘human impact period’. The calibrated SWAT associated with scenario 0 was executed considering the combinations of the aforementioned time periods/land use maps. The impacts of the climate variability and landuse change were calculated as follows:

Scenario 1: considering the climatic period 1997–2014 and landuse map of the year 1984

Scenario 2: considering the climatic period 1997–1984 and landuse map of the year 2001

Scenario 3: considering the climatic period 1997–2014 and landuse map of the year 2001


RESULTS AND DISCUSSIONS

Landuse change in different scenarios

The most important changes were among forests, rangelands, and agriculture. Other landuse such as rocky areas, cities, and water resources were only less than 2% of the whole region. Table 1 represents the area associated with different landuse classes. The most significant landuse changes occurred from the year 1984 to 2010. During this period, a great decline in forest areas and their conversion to agricultural and rangelands was observed. To elucidate on this, 72% of the area in 1984 was covered with forests; however, this percentage declined to 55% in 2010, which indicates a sharp decline in forest areas during this period. Most of these changes occurred in common border of forests. These changes occurred due to deterioration of trees and shrubs by foresters and villagers to supply fuel for domestic and livestock use, particularly in autumn and winter seasons. The ratio of forest regions to those of agriculture in 1984 was about 8, however, this ratio decreased to about 3 in 2010. Such changes during 2001–2010 were less than those of the period 1984–2001. Furthermore, the increase in agricultural lands was 100% in the first period. However, this declined to 13% in the second period. The results showed significant changes in the lands of Tajan River Basin during the last 26 years. In the period 1984–2010, the Hyrcanian forest areas were severely reduced and became mainly rangeland and agricultural lands. Agricultural activities are often chief drivers of land dynamics. Moreover, rangeland growth in the study area could be due to the fact that after converting forest use to agricultural use, agricultural lands do not have the necessary fertility after several cultivations, and thus these lands are abandoned and replaced by rangelands (Rajaei et al. 2018). This fact indicates that landuse planning is indispensable.

The study results of Joorabian-Shooshtari & Gholamali-fard (2015) in Neka River Basin in northern Iran showed that during 1979–2010, the decline in forest regions was 2600 hectares. The study of Vafaee et al. (2014) in the forests located in western Iran (Marivan) demonstrated that during the period 1989–2011, 1,334 hectares of forest lands were destroyed at a rate of 0.2% per year, and agricultural land increased in the region.

SWAT sensitivity analysis, calibration, and validation

After performing sensitivity analysis, the 10 parameters listed in Table 2 were determined as parameters to which the model was more sensitive, and the model was calibrated using these parameters and observed data in two stations of

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial range</th>
<th>Optimal range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOL_AWC (available water capacity of the soil layer)</td>
<td>0–1</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td>CN2 (SCS runoff curve number for moisture condition)</td>
<td>35–98</td>
<td>–0.2–0.1</td>
</tr>
<tr>
<td>EPCO (plant uptake compensation factor)</td>
<td>0–1</td>
<td>0.55–0.7</td>
</tr>
<tr>
<td>ESCO (outflow simulation option)</td>
<td>0–1</td>
<td>0.6–0.8</td>
</tr>
<tr>
<td>GW_REVAP (groundwater ‘revap’ coefficient)</td>
<td>0.02–0.2</td>
<td>0.03–0.06</td>
</tr>
<tr>
<td>GW_DELAY (groundwater delay)</td>
<td>0–500</td>
<td>18</td>
</tr>
<tr>
<td>GWQMN (threshold depth of water in the shallow aquifer required for return flow to occur)</td>
<td>0–5,000</td>
<td>150–300</td>
</tr>
<tr>
<td>SMTMP (snow melt base temperature)</td>
<td>–20–20</td>
<td>–4–4</td>
</tr>
<tr>
<td>HRU_SLP (average slope steepness)</td>
<td>0–1</td>
<td>–0.5–0</td>
</tr>
<tr>
<td>BIOMIX (biological mixing efficiency)</td>
<td>0–1</td>
<td>0.35–0.5</td>
</tr>
</tbody>
</table>
Kordkheil and Rig Cheshmeh stations. In the table, the initial and optimal range of each parameter is provided. In addition, the calibration and validation results are presented in Table 3 and Figure 3.

According to Moriasi et al. (2007), the results of the coefficient of determination, Nash-Sutcliffe as well as the \( r \)-factor and \( p \)-factor parameters derived from the model calibration and validation were satisfactory for both stations. This condition represents the model's ability to simulate runoff in the Tajan River Basin. The model's ability to

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rig Cheshmeh Station</th>
<th>Kordkheil Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R^2 )</td>
<td>0.67</td>
<td>0.60</td>
</tr>
<tr>
<td>NS</td>
<td>0.63</td>
<td>0.53</td>
</tr>
<tr>
<td>( p )-factor</td>
<td>0.70</td>
<td>0.49</td>
</tr>
<tr>
<td>( r )-factor</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Figure 3 | Observed and simulated runoff during calibration and validation period at Kordkheil station (a), Rigcheshme (b) stream-gauging stations during the calibration and validation periods.
simulate runoff in basins with different dimensions has been proven in Azimi et al. (2013) and Abbaspour et al. (2007). The basin has experienced a great deal of human interference. For instance, the existence of deviant channels upstream of hydrometric stations, particularly Kordkheil Station upstream, to transfer water to the surrounding agricultural lands. Moreover, a lack of written information from water transfer channels, as well as runoff entry from residential houses and industrial areas around the stations were the problems of model calibration and validation. Regarding landuse diversity in the basin, curve number parameter and maximum storage of forest canopy were separately calculated for different landuses. Also, simulated and calibrated LAI, ETact and crop yields (Figures 4 and 5) (Table 4).

![Figure 4](Simulated evaporation and actual evaporation reports from the National Water Act for crops in the study area.)

![Figure 5](Simulated yield and actual yield for crops in the study area.)
Streamflow simulation in different land use/climatic variables scenarios

Monthly flow response to different landuse scenarios

Simulated runoff under the three landuse scenarios (same climate scenario with different landuses) is presented in Figure 6. In all months of the year, the amount of runoff from scenario 1 (landuse in 2005) was smaller compared to those of scenario 2 (landuse in 2001) and scenario 4 (landuse in 2010). Scenario 4 yielded 3–21% and 0.8–13% more runoff values in Kordkheil station compared to those of scenario 1 and scenario 2, respectively. This increase is 3–19% and 2–12% in Rig Cheshmeh station.

Since landuse is the only variable during the 3 periods examined in this study, it can be concluded that these changes confirm the impact of landuse on the amount of runoff. The variations in runoff amount are more pronounced during 1984–2001 than 2001–2010, which is due to greater landuse changes during 1984–2001. The decline in forest area and increase in agricultural lands could result in a reduction in soil permeability, increase in de-watering, a decline in soil storage capacity and increase in runoff rate. On the other hand, since the soil in agricultural lands is unprotected in most months of the year, these lands have smaller effects in preventing rain drops falling on the surface of the soil, reducing interception and soil permeability, and increasing the CN value and the basin’s runoff. Moreover, forest areas, with their broad and deep roots, have high permeability soils. The decline in the forests reduces penetration of water from the root zone and ultimately increases the groundwater charge. Meanwhile, less water goes to the atmosphere and resultantly produces more rainfall and runoff water. Adverse effects of landuse change are not limited to reducing forests. Conversion of rangelands to lands that have not much ability to cover the surface of soil causes significant impacts on groundwater level, river flows and flooding of sub-basins and basins. The decline in rangelands leads to reduction in evaporation, infiltration, and organic matter; and an increase in bare soil area, runoff rate and transfer of nutrients. Hence, since a noticeable area of some sub-basins is covered with rangelands, it is essential to control/handle the landuse change approach (the conversion of satisfactory rangelands to other landuses) by propitious vegetation management and take a step forward by rehabilitation, modification, and development of such regions.

It is expected that in months with high precipitation, greater flow values are observed, while low precipitation results in relatively smaller flow values. In other studies,

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
<th>Orange</th>
<th>Rice</th>
<th>Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAI</td>
<td>Maximum potential leaf area index</td>
<td>4.5</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>HVSTI</td>
<td>Harvest index for optimal growing condition</td>
<td>0.9</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>DLAI</td>
<td>Fraction of growing season when leaf area begins to decline</td>
<td>0.7</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>FRGRW1 (%)</td>
<td>Fraction of the plant growing season or fraction of total potential of heat unit corresponding to the 1st point on the optimal leaf area develop curve</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>FRGRW2 (%)</td>
<td>Fraction of the plant growing season or fraction of total potential of heat unit corresponding to the 2nd point on the optimal leaf area develop curve</td>
<td>0.7</td>
<td>0.59–0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>LAIMX1 (%)</td>
<td>Fraction of the maximum area leaf index corresponding to the 1st point on the optimal leaf area develop curve</td>
<td>0.3</td>
<td>0.01</td>
<td>0.3</td>
</tr>
<tr>
<td>(%) LAIMX2</td>
<td>Fraction of the maximum area leaf index corresponding to the 2nd point on the optimal leaf area develop curve</td>
<td>0.8</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>T base (°C)</td>
<td>Minimum temperature for plant growth</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>T opt (°C)</td>
<td>Optimal temperature for plant growth</td>
<td>20</td>
<td>25</td>
<td>18–20</td>
</tr>
<tr>
<td>EXT_COEF</td>
<td>Light extinction coefficient</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>BIO_E ((kg/ha)/Mj/m²))</td>
<td>Radiation use efficiency or biomass energy ratio</td>
<td>70</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 4: The optimum values of plant parameters affecting crop yields
high runoff rates have usually been reported in high precipitation seasons (Zhang et al. 2017). According to the study carried out by Ghafari et al. (2009) the greatest runoff rates occurred in March, April and May in Zanjanrood, Iran. The reason for the rising runoff is the decrease in the maximum monthly precipitation of this basin, which coincides with the beginning of the warm/hot season (early spring) and snow melting within the basin.

Contrary to other studies, in this research the greatest runoff values are associated with those of April and July (Figure 6). This is due to the dams upstream of the area causing an alteration in the natural flow regime. In the spring and summer seasons, water is released from the dam to irrigate the plains areas, causing time variation in runoff water amount at the hydrometric stations. In Kordkheil station, the runoff is much reduced from April to September, indicating that it coincides with the time when agricultural lands are irrigated. Change in runoff did not have a linear trend relative to that of landuse. Furthermore, the research results of Kalantari et al. (2014) showed that the total deterioration of forests in the study area increased by only 6% of the runoff water. Moreover, in the study of Zare et al. (2016), the scenario of 60 and 30% forestation in the upstream and scenario of 30% forestation in the downstream decreased 14, 12 and 8% of runoff water. Moreover, Ghafari et al. (2009) studied the effects of landuse change in Zanjanrood River Basin using the SWAT model in order to simulate the main components of the water cycle. The results showed that hydrological response to overgrazing and the replacement of rangelands with agricultural and bare lands was nonlinear, and runoff increased dramatically when over 60% of the rangelands in the area were removed.
Therefore, the results were consistent with the study. In other words, it can be argued that the effect of the spatial location of landuse on the runoff is effective. In addition, the study of Kalantari et al. (2014) emphasizes the role of spatial characteristics of landuse on water quantity and quality.

Runoff response to different scenarios of climate change

The Intergovernmental Panel on Climate Change (IPCC) reports that the average temperature during the past 50 years has increased noticeably, while minor variations have occurred in the average global precipitation (Malekian & Kazemzadeh 2016). Long-term change in precipitation and average annual temperature in Tajan River Basin during 1984–2012 are represented in Figure 7. The annual temperature series during 30 years shows an increase of 2 °C in the average temperature. Furthermore, a decreasing change in precipitation was observed during the 30 years, but it was not noticeable. An increasing trend in temperature could increase evapotranspiration and water temperature, reduce precipitation and water resources (Sabziparvar et al. 2010; Dinpashoh et al. 2011). In addition, increase in water temperature could cause more ecological impacts on the Tajan's ecosystem services. Additionally, Khoshravesh et al. (2017) concluded that in general decreasing trends occurred in the

![Figure 7](http://iwaponline.com/ws/article-pdf/20/7/2779/788190/ws020072779.pdf)

**Figure 7** | Runoff response to different scenarios of climatic variables in (a) Kordkheil Station, (b) Rig Cheshmeh Station.
first 6 months of the water year (fall and winter) and increasing trends were associated with the second 6 months (spring and summer). For the 30-year period, the stations with decreasing trends are located in the east of province, which mostly includes Nekarood, Tajan, and Talar basins. Precipitation trend in 95% level of significance in Tajan River Basin is often decreasing, and it is meaningful at the 90% level of significance, indicating the significance of climate change in the study area. This could have serious consequences for the hydrology of the basin.

The study of climate variables in the two examined periods showed that during the period 1997–2013, the monthly precipitation in the basin increased in March and November and decreased in July compared to that of 1984–1997. In addition, the most monthly temperature variations are observed in February, March and August. Figure 8(a) and 8(b) demonstrate runoff variations under the impacts of change in climate variables for 2 climatic periods (same landuse) for two different hydrometric stations. In general, climate variables caused runoff water in both stations to decline, which could be to some extent due to an increase in evapotranspiration and temperature or decline in precipitation in most of the months. Increase in temperature may play a key role in the runoff variations during cold seasons, so that rising temperatures could reduce the effects of rising rainfall on the runoff.

The runoff varies at a rate of −0.3 to −5% at Kordkheil Station and 0 to −6 at Rig Cheshmeh Station. The maximum variations are related to summer and autumn seasons and the minimum ones belong to winter and early spring.
Regarding climatic variables in the second period, runoff decreased in summer and early autumn, and increased in winter and late autumn. The temperature also increased in summer and winter. Thus, it is expected that water flow increases in cold seasons and decreases in summer. It could be concluded that increase in temperature and decrease in precipitation in summer resulted in summers with higher temperatures during the second period. On the other hand, due to warmer winters, it is expected that greater flow would reduce in rainy seasons. However, there was no significant increase in Figure 8(a) and 8(b). Runoff correlates well with annual precipitation and temperature. Increase in temperature along with evapotranspiration could cause several consequences for the water balance of a basin. The present study highlights the potential impacts of changing climate variables in the hydrological status of the basin and points to the significance of attention to the issue of changing climate variables and its consequences in water resource management in the Tajan River Basin.

Abghari et al. (2015) studied river runoff and precipitation in western Iran during a 40-year period. They found strong relationships between annual runoff and precipitation and most months except January, February, July, and September. The results showed that the impacts of climate change on the runoff are less than land cover changes in the Tajan River Basin, which is due to the fact that in recent decades landuse changes in the Tajan River Basin have been more severe compared to those of other studies, so that Zhao et al. (2014) concluded that human activities were expected to have a greater impact on runoff than climatic variables. Furthermore, Li et al. (2007) concluded that human activities and climatic variables affect annual runoff by 87 and 13%, respectively, which is consistent with our study results. Zhang et al. (2008) showed that human and climatic variables shared the same contribution to runoff variations. However, Gao et al. (2015) reported that climate impacts will dominate outflow variations in the Puyang Basin, China, while land cover would have only an average impact. According to the results, the decreasing runoff trend in the region could be more affected by the vegetation degradation and human activities, thus contributing to increasing carbon dioxide and temperature of the area, and consequently the decline in effective precipitation.

According to the results, it is suggested that authorities and decision makers in the sectors of agriculture, water resources, environment, industry and economy ponder the necessary strategies such as saving water, reduction in utilization/consumption of surface and groundwater resources, change in the crop pattern, etc. to reduce the degrading consequences and adapt to the new climatic condition.

**DATA AVAILABILITY STATEMENT**

Data cannot be made publicly available; readers should contact the corresponding author for details.

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