Future projection of the effects of climate change on saffron yield and spatial-temporal distribution of cultivation by incorporating the effect of extreme climate indices

Saeedeh Kouzegaran, Mohamad Mousavi Baygi, Iman Babaeian & Abbas Khashei-Siuki

Theoretical and Applied Climatology

ISSN 0177-798X

Theor Appl Climatol
DOI 10.1007/s00704-020-03241-0

Springer

Theoretical and Applied Climatology
https://doi.org/10.1007/s00704-020-03241-0

ORIGINAL PAPER

Future projection of the effects of climate change on saffron yield and spatial-temporal distribution of cultivation by incorporating the effect of extreme climate indices

Saeedeh Kouzegaran[1] · Mohamad Mousavi Baygi[2] · Iman Babaeian[3] · Abbas Khashei-Siuki[4]

Received: 24 November 2019 / Accepted: 22 April 2020

Abstract
In this study, precipitation- and temperature-related indices were considered using Rclimdex software to study trend of climate extreme indices. Daily minimum and maximum temperature data retrieved from MPI-ESM-LR and ACCESS1-0 global climate model were used to predict future climate extreme events over the next three periods of 2026–2050, 2051–2075, and 2076–2100 based on IPCC scenarios of RCP4.5 and RCP8.5 of studied area covering South Khorasan province and southern part of Razavi Khorasan province, located in east of Iran; furthermore, future saffron yield was predicted based on the yield-extreme indices model. Results showed an increasing trend of warm climate extreme indices and a decreasing trend in precipitation indices as important factors in the decrease of saffron yield. Considering multiple regression yield model of saffron based on climate extreme indices, it was concluded that saffron yield decreases in future periods over studied area with the highest reduction of 31% in period of 2076–2100 under RCP8.5 scenario. Results also confirmed that yield reduction in all three periods under RCP8.5 scenario was greater than the same periods under RCP 4.5 scenario.

Keywords Saffron · Iran · Climate change · RCP scenarios · Climate extreme indices

1 Introduction

Climate change has a significant effect on agricultural activities, and its continuation will result in significant changes in food production and development processes as well as in production of agricultural systems at regional scale (Parry et al. 2004). Although farmers are unable to control climatic harmful conditions, but management measures such as change in some factors including spatial crop pattern, irrigation, soil, cultivar, crop, activities, and technologies used in crop cultivation can play a significant role in reducing harmful effects of climate change on growth and yield of agricultural products. Living creatures including plants have adapted to their environment over a long period of time and adapted their growth stages to environmental conditions. In this regard, any changes in climate make significant changes in growth of the plants, and depending on severity of changes, it may cause their spatial and temporal relocations and eventually, their removal from agricultural systems of a specific area (Horie et al. 2000). As such, relocation of maize from southern Europe to the north, specifically Denmark and Norway, was due to temperature changes (Ewert et al. 2005). Some crops undergo such phenomena, and this has been globally confirmed by scientific resources. Powell and Reinhard (2016) studied trend of climate extreme events and their effect on winter wheat yield in the Netherlands. They showed that number of days with high extreme temperatures in wheat growing areas has increased significantly since 1900, while number of days with low extreme temperature has reduced in this period. Investigation of the effect of weather extreme events on wheat yield over a time period showed that high temperature and precipitation extreme events have caused a significant decrease in the yield. Tian et al. (2017) analyzed the effects of temperature and precipitation extreme

---

✉ Saeedeh Kouzegaran
saeedeh.kouzegaran@mail.um.ac.ir

[1] Water Engineering Department, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

[2] Water Engineering Department, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

[3] National Climate Research Institute, Mashhad, Iran

[4] Water Engineering Department, Faculty of Agriculture, University of Birjand, Birjand, Iran

indices on spatial and temporal distribution in major cereal production regions during 1961–2011. Their results showed a significant upward trend in warm extreme events and a decreasing trend in cold extreme events in most regions. Trend of precipitation extreme events was often insignificant. They also showed that occurrence and trend of extreme events influence wheat yield. Also, decreasing trend of frost days (FD) as well as increasing trend of highest monthly maximum temperature (TXx) and warm days (SU25) decreased wheat yield. Barlow et al. (2015) simulated and investigated the effect of cold and hot extreme events on wheat production. Hatfield and Prueger (2015) in a study on the relationship between temperature extreme events and plant growth and development found that high extreme temperatures during reproductive stage have a major effect on maize yield and reduced yield by 80–90% compared with normal heat regime. Under climate change conditions, many areas of Iran will experience reduced precipitation and increased temperatures (Fallahi et al. 2013). These changes will have significant effects on crop growth, area of crop distribution, length of growing season, and pattern of planting in different areas. Temperature is, undoubtedly, the most important environmental factor controlling many physiological processes of plants and flowering stage, as the most important stage of plant development is regulated by temperature (Atkinson and Porter 1996). Increasing temperature will severely influence flowering patterns of plants (Menzel 2000). Growing season of saffron is in cold season, where its aerial parts come out of the soil and grow. Flowering of saffron is among unique processes of the plant occurring before beginning of vegetative growth. Halevy (1989) believes that temperature can be the most important regulator of saffron flowering. Numerous studies (Behdani et al. 2003; Molina et al. 2004) have shown that minimum temperature is main determinant of flower formation in saffron. In areas with earlier than normal onset of cold temperature (in cold season), saffron flowering begins earlier. Due to strong correlation between saffron flowering behavior and ambient temperature, it seems that future climate change will influence flowering patterns of this plant (Koocheki 2003). Precipitation has a great effect on growth of roots. Changing precipitation patterns along with increasing evaporation caused by warming will increase water requirement of the plant and limiting plant yield. Investigating trend of saffron yield in the last few years shows that, while the area of lands under saffron cultivation has increased in the country, yield per unit area has decreased. Considering significant influence of climate extreme indices at saffron yield, it is important to quantify amount and pattern of climate extreme events and their effects on saffron yield.

According to above explanations and due to strong correlation between saffron behavior, temperature, and precipitation, climate extreme events and future climate change seem to influence saffron cultivation and yield. Thus, in this study, saffron crop systems and meteorological parameters and extreme indices influencing saffron production in east of Iran will be investigated. In addition, the effect of future climate change extreme events on spatial and temporal variations of saffron cultivation and yield will be studied. Future saffron yield was predicted based on the yield-extreme indices model.

2 Materials and methods

2.1 Studied region and data

Saffron is one of the most important agricultural crops in Iran. The regions studied in this research included Southern Khorasan province and south of Khorasan Razavi province (Fig. 1), which are the most popular centers for saffron production in this country. Altitudes between 1300 and 2300 meters are the most suitable for growing saffron, in Iran (Sobhani 2016). In this study, long-term data of daily precipitation, minimum, and maximum temperature of 9 synoptic stations in the region were used within the period of 1991–2015.

2.2 Global climate models

In this study, data of daily minimum and maximum temperatures were obtained with a spatial resolution of 0.44° in MPI-ESM-LR model under RCP4.5 scenario as a moderate case, and RCP8.5 as the worst case of Representative Concentration Pathway (RCP) scenarios. MPI-ESM-LR data was retrieved from CORDEX project.

According to the study by Sillmann et al. (2013), ACCESS1-0 is one of global climate models simulating precipitation indices relatively well and performing better than other models. ETCCDI Expert Team introduced ACCESS1-0 global climate model as a superior model in simulating extreme precipitation indices, needed as an input to simulate the effect of climate extremes on saffron yield. RCP4.5 and RCP8.5 scenarios' data were used for modeling of climate extremes. Model data were used for study areas in historical period of 1991–2015 and the three following future periods: 2026–2050, 2051–2075, and 2076–2100. The specifications of studied models are displayed in Table 1.

2.3 Downscaling of global climate model data

2.3.1 Downscaling of temperature

-Modified BCSD method The BCSD (bias correction and standard deviation) statistical downscaling method includes two steps of bias correction and data generation. In bias correction step, averaged values of general circulation model (GCM) in base period are compared with observed data at the same period. Then, GCM simulations are corrected in future period

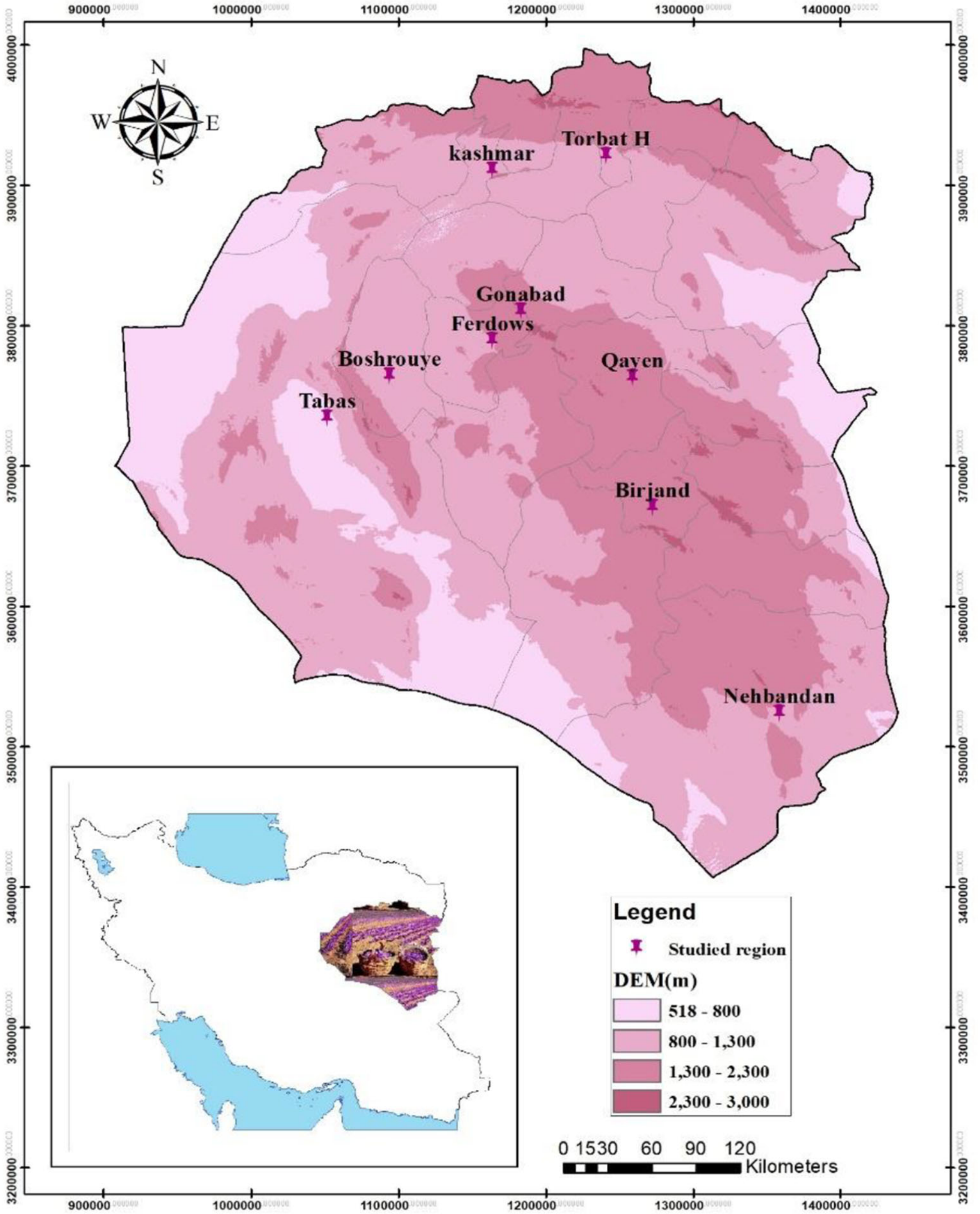

Fig. 1 The geographical location and digital elevation model (DEM) of the studied region

based on resulted bias. This method (BCSD) is based on a comparison between cumulative distribution function (CDF) of observed climate data and output of GCM over a same period, and assumes that the model bias follows a similar pattern in both model data in the present and future climate conditions (Ahmed et al. 2013).

Since the aim of this study is investigating extreme indices and bias of extreme indices that are different from mean

Table 1 Specifications of studied models

Institute	Modeling center (or group)	Country	Model name	Atmosphere resolution	Received data from
CSIRO-BOM	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM)	Australia	ACCESS1.0	N96 (1.25°*1.87°) L38	Canadian Centre for Climate Modelling and Analysis (CCCma)
MPI-M	Max Planck Institut for Meteorologie	Germany	MPI-ESM-LR	T63 (1.875°*1.875°) L47	The Earth System Grid Federation (ESGF)

climate, in this regard, to downscale extreme temperature data, a different BCSD downscaling method was applied for different percentiles. High percentiles were considered for maximum temperature and low percentiles for minimum temperature. Then, proportionate BCSD pattern was applied for high (maximum) and low (minimum) percentiles.

2.3.2 Downscaling of precipitation extreme indices

BCMV (bias correction and mean variance) method was used for downscaling of precipitation output to compute precipitation indices influencing saffron yield. In this method, transfer function is determined for each model by comparing historical output of model with observations, according to which future model data are shifted. In this method, temporal structure of the model output (GCM) is retained because transfer function is performed on the model output. Variance of predictions is also improved in this method. This method is based on the following equation (Pinya et al. 2015):

$$P_{y,j}^{Fut} = a_j \left(P_{y,j}^{RCMFut}\right)^{b_j} \tag{1}$$

where a_j is alpha transfer function and is obtained by dividing observed mean by control/historical mean, b_j is obtained by equalizing coefficient of variation $\left(a_j P_j^{RCMCon}\right)^{b_j}$ and $P_j^{obs} b_j$. b_j is determined by iteration since it is not possible to solve this equation in closed form.

3 Prediction of climate extreme events and estimating future saffron yield

After downscaling of GCM model data, the data were classified in the next three periods of 2026–2050 (near future), 2051–2075 (midterm future), and 2075–2100 (far future) based on RCP4.5 and RCP8.5 scenarios for all studied stations. For each period, temperature extreme indices were estimated using RClimdex. Trends of extreme indices were also evaluated.

3.1 Prediction and estimation of saffron yield in the future

A multiple linear regression model (Eq. (2)) was designed to estimate saffron yield by incorporating climate extreme indices. Full description on multiple regression model is presented in the study by Kouzegaran et al. (2020), who studied the relationship between saffron yield and extreme indices. Using Eq. (2), saffron yield can be estimated in kg/ha.

$$\begin{aligned} Yield = {} & 3.3995269 - 0.019821 * SU25 - 0.007078 * TR20 \\ & - 0.11502 * TNx + 0.072022 * TX10P + 0.0307757 \\ & * TXn + 0.165546 * TXx + 0.0032438 * PRCPTOT \\ & - 0.044026 * SDII \end{aligned} \tag{2}$$

The model involves the index of summer days (SU25), number of tropical nights (TR20), maximum monthly daily minimum temperature (TNx), the index of cold days (TX10P), the minimum monthly daily maximum temperature (TXn), the maximum monthly daily maximum (TXx), annual precipitation on wet days (PRCPTOT), and simple daily intensity index (SDII).

Equation (2) shows high R^2, good correlation (0.68), and low RMSE (0.6). Prediction power of the model with NRMSE (14.1) was considered to range from good to excellent, and error rate of saffron yield model was estimated to be 9.5%.

Applying Eq. (2), saffron yield was estimated for the three future periods of 2026–2050, 2051–2075, and 2076–2100. Saffron yield zoning map was created based on yield-extreme indices model for each future period considering RCP4.5 and RCP8.5 scenarios.

4 Results and discussion

4.1 Prediction of future climate extreme events

Previous studies suggested that climate change will have negative effects on agricultural production, and these negative effects are extremely severe in hot and dry regions. Therefore, climate predictions are essential for macro-scale planning in these areas. In this study, trend of temperature extreme indices influencing saffron yield and model parameters was investigated in the three future periods of 2026–2050, 2051–2075, and 2076–2100 based on RCP4.5 and RCP8.5 scenarios.

4.2 Investigating trend of temperature extreme indices influencing yield in future periods based on RCP4.5 scenario using MPI-ESM-LR model

According to the output of Rclimdex for RCP4.5 scenario in the period of 2026–2050, it was observed that SU25 index, summer days, has a positive trend at all studied stations, and this trend is statistically significant for Torbat Heydariyeh station. This index was found to be significant and increased at all stations in midterm future period, and it had an increasing trend in far future period, which was not significant. Number of tropical nights (TR20) index had a positive trend at all stations, and this trend was significant at the stations of Birjand, Boshruyeh, Ferdows, Tabas, Torbat Heydariyeh, and Gonabad. In midterm future period, there was a

Table 2 Investigating trend of temperature extreme indices influencing yield in future periods based on RCP4.5 scenario using MPI-ESM-LR model

Period	Index		Birjand	Boshrouye	Ferdows	Nehbandan	Qayen	Tabas	Torbat heydarie	Kashmar	Gonabad
2026-2050	SU25	Summer days	⇧	⇧	⇧	⇧	⇧	⇧	⬆	⇧	⇧
	TR20	Tropical nights	⬆	⬆	⬆	⇧	⇧	⬆	⬆	⇧	⬆
	TXx	Maximum Tmax	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TNx	Tmin Maximum	⇧	⇧	⇧	⇧	⇧	⬆	⇧	⇧	⇧
	TXn	Minimum Tmax	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	TX10p	Cold days	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩
2051-2075	SU25	Summer days	⬆	⬆	⬆	⬆	⇧	⬆	⇧	⇧	⬆
	TR20	Tropical nights	⇧	⇧	⇧	⇧	⬆	⇧	⇧	⬆	⇧
	TXx	Maximum Tmax	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆
	TNx	Tmin Maximum	⬆	⬆	⬆	⬆	⇧	⬆	⬆	⬆	⬆
	TXn	Minimum Tmax	⇩	⇩	⇩	⇩	⇩	⇧	⇩	⇩	⇧
	TX10p	Cold days	⬇	⬇	⬇	⬇	⬇	⬇	⬇	⬇	⬇
2076-2100	SU25	Summer days	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TR20	Tropical nights	⇧	⇩	⇩	⇩	⇩	⇩	⇩	⇧	⇧
	TXx	Maximum Tmax	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	TNx	Tmin Maximum	⇩	⇩	⇩	⇩	⇩	⬇	⇩	⇧	⇩
	TXn	Minimum Tmax	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆
	TX10p	Cold days	⇧	⇩	⇩	⇩	⇩	⇩	⇧	⇩	⇩

Bold arrows in front of units are significant (5% significance level)

Upward arrows stand for an increasing trend

Downward arrows stand for a decreasing trend

significant increasing trend for some stations, while in far future, there were some negative and insignificant trends at some stations. Percentage of days on which maximum temperature is below than the 10th percentile (TX10P), indicating a decrease in the number of cold days, had a negative significant trend for all stations except Ferdows, obtained by fitting curve of cold day's index. This index had a negative significant trend for midterm future, and a decreasing insignificant tend for most stations studied over far future period. The maximum monthly daily maximum temperature (TXx) and the maximum monthly daily minimum temperature (TNx) indices also had an increasing trend at all stations, and midterm future period had a significant increasing trend, while the trend was decreasing in far future period. The minimum monthly daily maximum temperature (TXn) had a negative trend during near

Table 3 Investigating trend of temperature indices influencing yield in future periods based on RCP8.5 scenario using MPI-ESM-LR model

Period	Index		Birjand	Boshrouye	Ferdows	Nehbandan	Qayen	Tabas	Torbat heydarie	Kashmar	Gonabad
2026-2050	SU25	Summer days	⇧	⬆	⇧	⬆	⇧	⇧	⬆	⇧	⇧
	TR20	Tropical nights	⬆	⇧	⇧	⇧	⇧	⬆	⬆	⬆	⬆
	TXx	Maximum Tmax	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TNx	Tmin Maximum	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TXn	Minimum Tmax	⇧	⇧	⇧	⇧	⇧	⬆	⇧	⇧	⇧
	TX10p	cold days	⇩	⇩	⇩	⬇	⇩	⇩	⇩	⬇	⇩
2051-2075	SU25	Summer days	⬆	⇧	⬆	⇧	⬆	⬆	⇧	⬆	⬆
	TR20	Tropical nights	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⇧	⬆
	TXx	Maximum Tmax	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⬆
	TNx	Tmin Maximum	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⇧	⬆
	TXn	Minimum Tmax	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩
	TX10p	Cold days	⬇	⬇	⬇	⬇	⬇	⬇	⬇	⇩	⬇
2076-2100	SU25	Summer days	⬆	⬆	⬆	⬆	⬆	⬆	⇧	⬆	⬆
	TR20	Tropical nights	⬆	⬆	⬆	⬆	⬆	⬆	⬆	⇧	⇧
	TXx	Maximum Tmax	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TNx	Tmin Maximum	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
	TXn	Minimum Tmax	⇧	⬆	⬆	⇧	⇧	⇧	⇧	⇧	⬆
	TX10p	Cold days	⬇	⬇	⬇	⬇	⬇	⬇	⇩	⬇	⬇

Bold arrows in front of units are significant (5% significance level)

Upward arrows stand for an increasing trend

Downward arrows stand for a decreasing trend

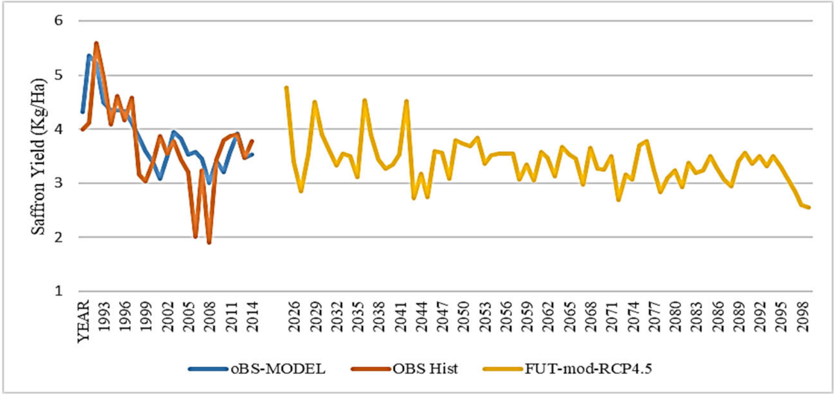

Fig. 2 Changes in saffron yield in observed period (1991–2015), along with historical data of yield during observed period, and saffron yield based on the yield-extreme indices model in future periods according to RCP4.5 scenario

and midterm future periods, while it had a positive significant trend in far future period (Table 2).

4.3 Investigating trend of temperature extreme indices influencing yield in future periods based on RCP8.5 scenario using MPI-ESM-LR model

Temperature extreme indices were computed using Rclimdex under RCP8.5 scenario using MPI-ESM-LR model data in studied periods. Results showed that SU25 index, i.e., summer days had a positive trend at all stations studied in near future period, which was found to be significant in Boshrouyeh, Torbat Heydariyeh, and Nehbandan stations. There was also an increasing significant trend at all stations except Torbat Heydariyeh in midterm and far future periods. Index of tropical nights (TR20) had an upward trend, which was significant in midterm and far future periods at most stations. Percentage of days in which maximum temperature is below than the 10th percentile (TX10P), indicating a decrease in cold days, had a negative trend for all stations in near future period. In midterm and far future periods, this trend was significant at all stations. The maximum monthly daily maximum temperature (TXx) and the maximum monthly daily minimum temperature (TNx) indices also had an increasing trend at all stations and all three periods, and the trend was significant in midterm future. At all stations, TXn had a positive trend in near and far future periods, but it had a decreasing, although not significant trend in midterm future period (Table 3).

4.4 Investigating trend of extreme precipitation indices studied in future periods

Results obtained from ACCESS1-0 global climate model for RCP4.5 and RCP8.5 scenarios showed that precipitation indices influencing on yield exhibit different patterns in terms of intensity, duration, and frequency of precipitation. PRCPTOT index, annual precipitation on wet days, was found to fluctuate over the years; however, the index had a negative trend at all stations, and a significant decrease was observed in the precipitation in studied region. This decrease was observed in all three studied periods, and as expected, decreasing trend of precipitation was more prominent according to RCP8.5 scenario. The simple daily intensity index (SDII), annual total precipitation divided by the number of wet days, had high fluctuation and did not follow a specific pattern, but it had a decreasing trend at almost all stations over the three studied

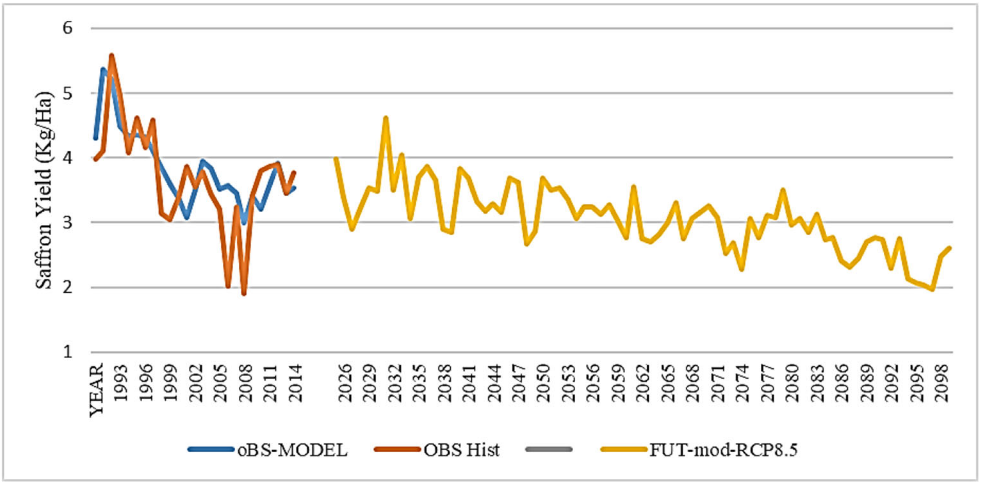

Fig. 3 Changes in saffron yield in observed period (1991–2015), along with historical data of yield during observed period, and saffron yield based on the yield-extreme indices model in future periods according to RCP8.5 scenario

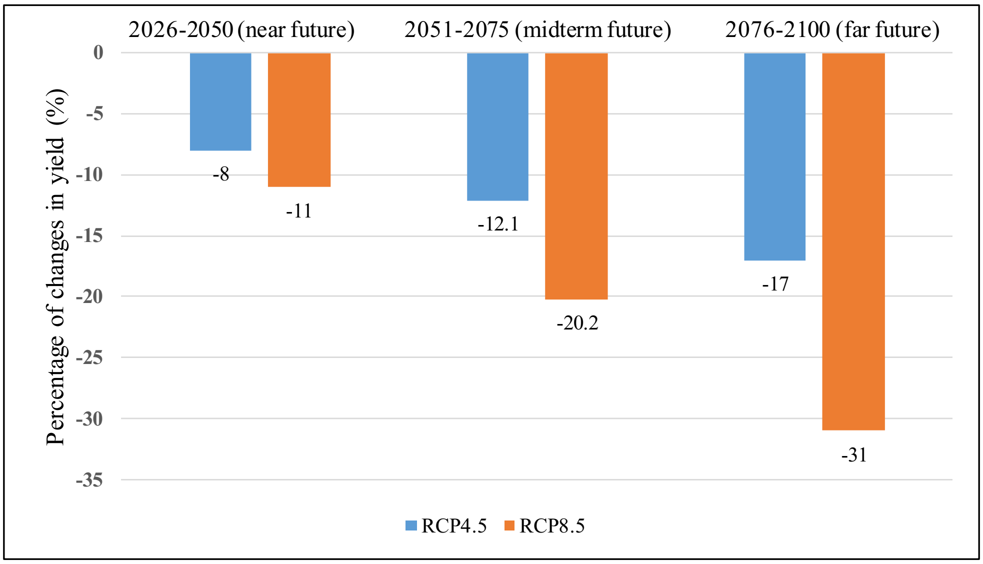

Fig. 4 Percentage of changes in saffron yield during three future periods under RCP8.5 and RCP4.5 scenarios taking into account changes in extreme events based on yield-extreme event model

periods. Investigation of precipitation indices showed that there was a negative and decreasing trend of precipitation at all studied stations. Meanwhile, there were only a small number of significant trends over the three studied future periods. Comparison of the lowest and highest precipitation years showed that precipitation fluctuations are very high among the years, and temporal distribution of precipitation varies at different stations.

4.5 Prediction of saffron yield in future periods

Results of this study showed that temperature extreme events have increased while precipitation parameters followed a decreasing trend. Considering estimated trends and their influence on saffron, a decrease was estimated in saffron yield in the three future periods under RCP4.5 and RCP8.5 scenarios (Figs. 2 and 3). Based on developed model (Eq. (2)) and simulation of saffron yield under future climate change conditions according to RCP4.5 scenarios, saffron yield was predicted to be reduced by 8% in study area during period of 2026–2050, followed by 12.1% reduction in period of 2051–2075 and 17% reduction in period of 2076–2100. As expected, yield reduction under RCP8.5 scenarios will be greater than that of RCP4.5 scenario so that yield reduction in the three studied periods was obtained as 11, 20.2, and 31%, respectively (Fig. 4).

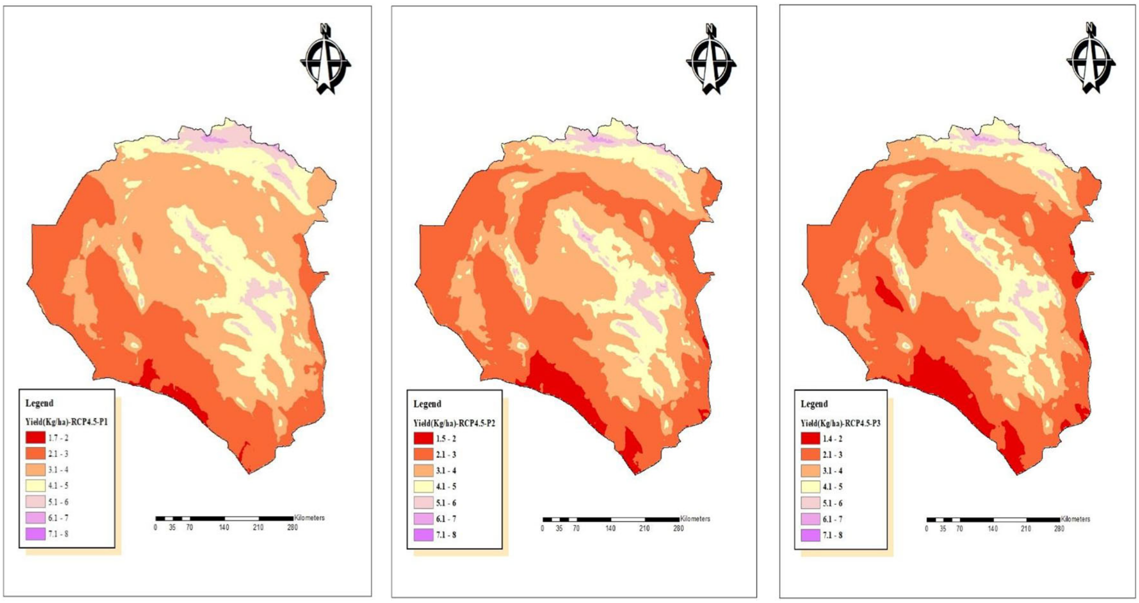

Fig. 5 Saffron yield zoning maps based on yield-extreme indices model in three future periods according to RCP4.5 scenario

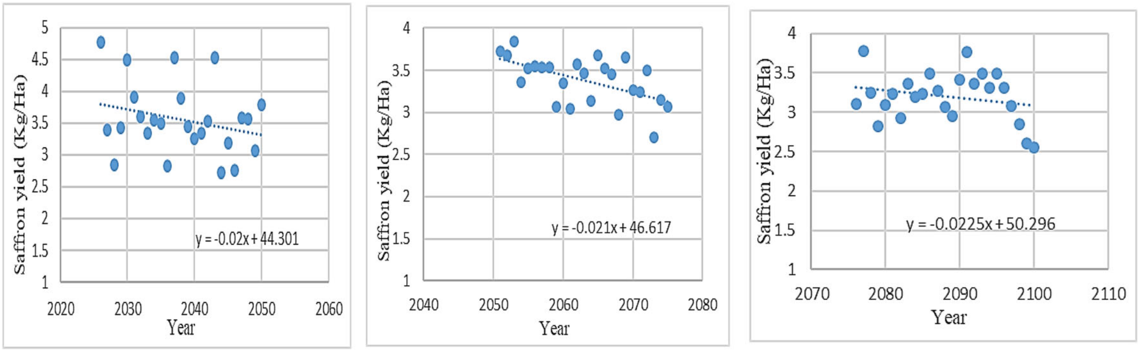

Fig. 6 Changes in the saffron yield based on yield-extreme event model in three future periods under RCP4.5 scenario

The highest reduction in saffron yield will be under RCP8.5 scenario during 2075–2100, such that in other periods, the yield will be eliminated in classes 7 and 8 (kg/ha), and during 2075–2100, under RCP8.5 scenario, three classes of the yield will be eliminated completely during 5, 6, and 7 (kg/ha) yield intervals (Fig. 5, 6, 7, and 8), revealing a significant reduction of the yield in this period.

Changes in saffron yield based on yield-extreme event model with observed data in period of 1991–2015, as well as historical data and RCP scenarios data are shown in the following diagrams.

In this study, the trend of climate extreme indices and their effect on saffron yield were investigated during future periods. During the three studied future periods, extreme temperature and precipitation indices have changed significantly. These increased warm temperature extreme events, as well as decrease precipitation, can reduce saffron yield significantly. These changes have caused spatial and temporal dislocations in saffron yield. These results are in line with results of regional and global studies. Results of the present study are consistent with results of the studies by Kouzegaran et al. (2011, 2013, 2018), Molina et al. (2005), and Behdani et al. (2003) on the influence of climate factors on saffron yield and also the study by Koocheki (2003) on modeling of the effect of climate change on saffron flowering behavior, who indicated that due to global warming, flowering will be delayed in Khorasan Razavi and Southern Khorasan provinces depending on intensity of warming. This study is also in line with other studies on the effects of changes on climate extreme indices in relation to reduction of crop yields (Barlow et al. 2015; Im et al. 2011; Jin et al. 2017; Koocheki et al. 2006; Lashkari et al. 2011; Lhomme et al. 2009; Powell and Reinhard 2016; Tian et al. 2017).

5 Conclusion

Previous studies demonstrated that climate change has a negative effect on agricultural productions, and this effect is very

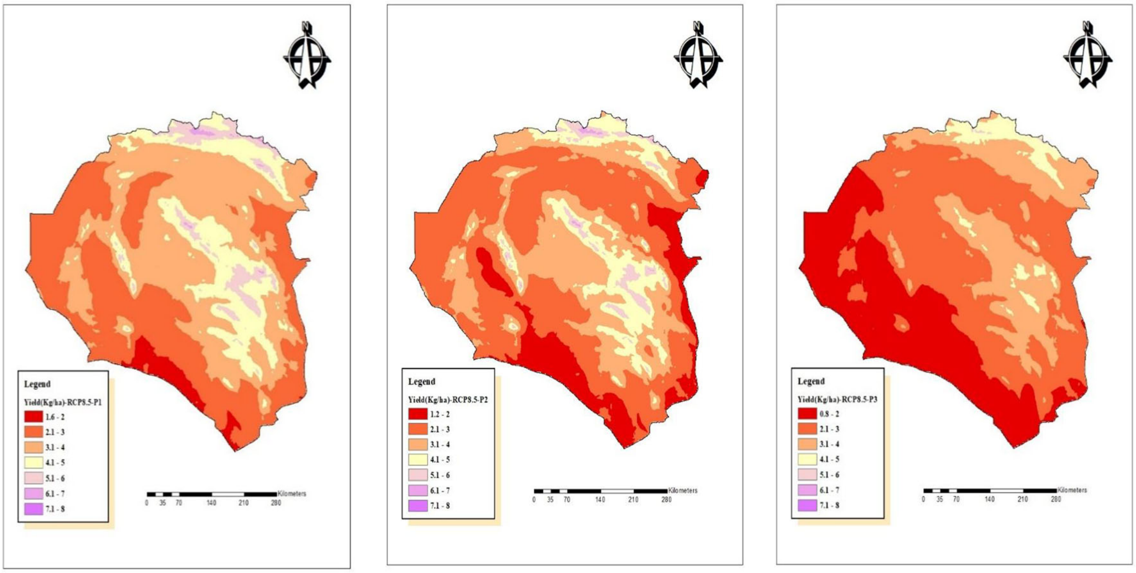

Fig. 7 Saffron yield zoning maps based on yield-extreme indices model in three future periods according on RCP8.5 scenario

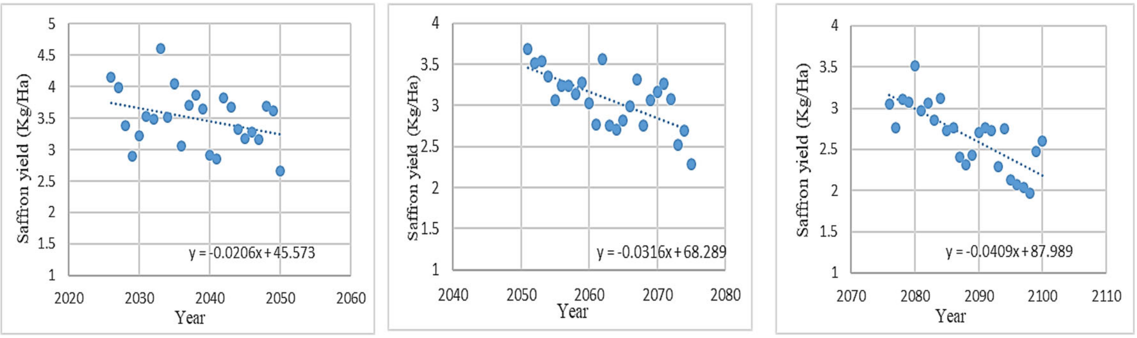

Fig. 8 Changes in the saffron yield based on yield-extreme event model in the 2075–2100 periods under RCP8.5 scenario

severe in warm and arid climates. Future projection of saffron yield in east of Iran was the main objective of the current study. Data on observed climatology and saffron yield together with GCM model data in historical and future periods were used. A multiple linear regression climate extreme-yield model was used for modeling of saffron yield under different climate extreme indices and RCP scenarios. Minimum and maximum daily temperatures from MPI-ESM-LR model and precipitation from ACCESS1-0 global climate model were used to predict climatic extreme events during three future periods of 2026–2050, 2051–2075, and 2076–2100 under RCP4.5 and RCP8.5 scenarios at all stations located in South Khorasan province and southern part of Khorasan Razavi province in east of Iran.

Temperature extreme indices including the number of summer days (SU25), number of tropical nights (TR20), the maximum monthly daily minimum temperature (TNx), cold days (TX10P), the minimum monthly daily maximum temperature (TXn), and the daily maximum temperature (TXx) are the indices influencing saffron yield. Considering importance of minimum temperature in saffron yield, an increase in the index of warm nights and maximum Tmin negatively influences saffron yield, and therefore, understanding of the changes in these indices is necessary for prediction of saffron yield. A decrease in the TX10P index decreases saffron yield. Kouzegaran et al. (2011) in their study on the effects of minimum, mean, and maximum temperatures on saffron yield showed that yield increases where maximum temperature is lower, and that there is a reverse correlation between maximum temperature and yield. Therefore, an increase in the warm extreme indices such as SU25, summer days, could be the reason for a decrease in the saffron yield.

Decreased precipitation could have a negative effect on saffron yield. According to prediction model of saffron yield-extreme climate indices, annual precipitation on wet days (PRCPTOT) and the simple daily intensity index (SDII) were considered as extreme indices of precipitation influencing saffron yield. So, negative and decreasing trend of annual precipitation on wet days (PRCPTOT) and negative and decreasing trend of the simple daily intensity index (SDII) in future periods could be major reasons for reduced yield in studied region. It was found that saffron yield will be decreased by 8% during the period of 2026–2050, followed by 12.1% reduction in the period of 2051–2075, and 17% reduction in the period of 2076–2100 under RCP4.5 scenario, while it was obtained as 11, 20.2, and 31% under RCP8.5 scenario, which is greater than RCP4.5 scenario.

Results of this study indicated important role of changes in temperature and precipitation extreme events in saffron yield. Decreasing trend of saffron yield, as the most important agriculture product over studied region, reveals the need for extensive regional planning to mitigate negative effect of global warming over the region.

References

Ahmed KF, Wang G, Silander J, Wilson AM, Allen JM, Horton R, Anyah R (2013) Statistical downscaling and bias correction of climate model outputs for climate change impact assessment in the US northeast. Glob Planet Chang 100:320–332

Atkinson D, Porter JR (1996) Temperature, plant development and crop yields. Trends Plant Sci 1:119–124

Barlow K, Christy B, O'leary G, Riffkin P, Nuttall J (2015) Simulating the impact of extreme heat and frost events on wheat crop production: a review. Field Crop Res 171:109–119

Behdani MA, Nassiri M, Koocheki AA (2003) Modeling saffron flowering time across a temperature gradient. I Int Symp Saffron Biol Biotechnol 650:215–218

Ewert F, Rounsevell M, Reginster I, Metzger M, Leemans R (2005) Future scenarios of European agricultural land use: I. estimating changes in crop productivity. Agriculture. Ecosyst Environ 107: 101–116

Fallahi J, Rezvani MP, NasiriI MM, Behdani M (2013) Validation of RothC model for evaluation of carbon sequestration in a restorated ecosystem under two different climatic scenarios. J Water Soil:656–668

Halevy A (1989) Recent advances in control of flowering and growth habit of geophytes. V Int Symp Flower Bulbs 266:35–42

Hatfield JL, Prueger JH (2015) Temperature extremes: effect on plant growth and development. Weather Clim Extremes 10:4–10

Horie T, Baker JT, Nakagawa H, Matsui T, Kim HY (2000) Crop ecosystem responses to climatic change: rice. Clim Chang Glob Crop Prod:81–106

Im E, Jung I, Bae DJ (2011) The temporal and spatial structures of recent and future trends in extreme indices over Korea from a regional climate projection. Int J Climatol 31:72–86

Jin Z, Zhuang Q, Wang J, Archontoulis SV, Zobel Z, Kotamarthi VR (2017) The combined and separate impacts of climate extremes on the current and future US rainfed maize and soybean production under elevated CO2. Glob Chang Biol 23:2687–2704

Koocheki AA (2003) Indigenous knowledge in agriculture with particular reference to saffron production in Iran. I Int Symp Saffron Biol Biotechnol 650:175–182

Koocheki A, Nassir M, Jamali J, Marashi H (2006) Evaluation of the effects of climate change on growth characteristics and yield of rainfed wheat in Iran. Agric Sci 20:83–95

Kouzegaran S, Mousavi BM, Sanaeinejad H, Behdani MA (2011) Study of the minimum, average and maximum temperature in South Khorasan to identify relevant areas for saffron cultivation using GIS. J Water Soil 25:892–904

Kouzegaran S, Mousavi Baygi M, Sanaeinejad H, Behdani M (2013). Identification relevant areas for saffron cultivation according to precipitation and relative humidity in South Khorasan using GIS. J Saf Res 1(2):85–96. https://doi.org/10.22077/jsr.2013.436

Kouzegaran, S., Mousavi Baygi, M., Khashei-Siuki, A., Babaeian, I. (2018). Modeling of the Saffron Yield Based on Meteorological Extreme Events (Case study: Birjand). J Saf Res 5(2):217–229. https://doi.org/10.22077/jsr.2017.411.1017

Kouzegaran S, Mousavi Baygi M, Babaeian I, Khashei-Siuki A (2020) Modeling of the saffron yield in Central Khorasan region based on meteorological extreme events. Theor Appl Climatol 139:1207–1217

Lashkari A, Alizadeh A, Bannayan M (2011) Investigation of mitigation of climate change impacts on maize production in Northeast of Iran. J Water Soil 25:926–939

Lhomme J-P, Mougou R, Mansour M (2009) Potential impact of climate change on durum wheat cropping in Tunisia. Clim Chang 96:549–564

Menzel A (2000) Trends in phenological phases in Europe between 1951 and 1996. Int J Biometeorol 44:76–81

Molina R, Valero M, Navarro Y, Garcıa-Luis A, Guardiola J (2004) The effect of time of corm lifting and duration of incubation at inductive temperature on flowering in the saffron plant (Crocus sativus L.). Sci Hortic 103:79–91

Molina R, Valero M, Navarro Y, Guardiola J, Garcia-Luis A (2005) Temperature effects on flower formation in saffron (Crocus sativus L.). Sci Hortic 103:361–379

Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Chang 14:53–67

Pinya MAS, Hundecha Y, Lawrence D, Madsen H, Willems P, Martinkova M, Vormoor K, Bürger G, Hanel M, Kriaučiuniene J (2015) Inter-comparison of statistical downscaling methods for projection of extreme precipitation in Europe. Hydrol Earth Syst Sci 19:1827–1847

Powell J, Reinhard S (2016) Measuring the effects of extreme weather events on yields. Weather Clim Extremes 12:69–79

Sillmann J, Kharin V, Zhang X, Zwiers F, Bronaugh D (2013) Climate extremes indices in the CMIP5 multimodel ensemble: part 1. Model evaluation in the present climate. J Geophys Res Atmos 118:1716–1733

Sobhani B (2016) Agroclimatic zoning cultivation Saffron in Ardabil Province using of method AHP. J Saf Res 4(1):72–86

Tian J, Liu J, Wang J, Li C, Nie H, Yu F (2017) Trend analysis of temperature and precipitation extremes in major grain producing area of China. Int J Climatol 37:672–687