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ORIGINAL ARTICLE

# Future production of rainfed wheat in Iran (Khorasan province): climate change scenario analysis

**Mohammad Bannayan · Ehsan Eyshi Rezaei**

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**Abstract** Projecting staple crop production including wheat under future climate plays a fundamental role in planning the required adaptation and mitigation strategies for climate change effects especially in developing countries. The main aim of this study was to investigate the direction and magnitude of climate change impacts on grain yield of rainfed wheat (*Triticum aestivum L.*) production and precipitation within growing season. This study was performed for various regions in Khorasan province which is located in northeast of Iran. Climate projections of two General Circulation Models (GCM) for four locations under three climate change scenarios were employed in this study for different future time periods. A stochastic weather generator (LARS-WG5) was used for downscaling to generate daily climate parameters from GCMs output. The Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5 was employed to evaluate rainfed wheat performance under future climate. Grain yield of rainfed wheat and precipitation during growth period considerably decreased under different scenarios in various time periods in contrast to baseline. Highest grain yield and precipitation during growth period was obtained under B1 scenario but A1B and A2 scenarios resulted in sharp decrease (by −57 %) of grain yield. Climate change did not have marked effects on evapotranspiration during the rainfed wheat growth. A significant correlation was detected between grain yield, precipitation and evapotranspiration under climate change for both GCMs and under all study scenarios. It was concluded, that rainfed wheat production may decline during the next 80 years especially under A2 scenario. Therefore, planning the comprehensive adaptation and mitigation program is necessary for avoiding climate change negative impact on rainfed wheat production.

**Keywords** Climate change · Crop growth simulation · General circulation models · Rainfed-wheat yield · Precipitation

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## 1 Introduction

Crop growth and yield under normal and severe conditions are largely determined by climatic variability during the growing season (Mall et al. 2004). Climate change will probably have a negative impact on tropical and temperate regions and any other areas where high temperature or inadequate rain often limits crop productivity (Morison and Morecroft 2006). Based on the General Circulation Models (GCM) projections, future changes of global average temperature are expected to increase between 2 °C and 4.5 °C in this century (IPCC 2007). The main constraint in assessing risk from climate change is the lack of long-term weather data and man's inability to predict the future weather (Abraha and Savage 2006) however development of various useful tools are increasing (Bannayan and Hoogenboom 2008). Climate change is expected to have a profound influence on crop production sustainability in arid and semi arid environments like Iran. Crop production in dryland regions is mainly determined by precipitation and is extremely vulnerable to changes in precipitation patterns and amounts. This vulnerability increases with decrease in total precipitation. Among agricultural crops, wheat (*Triticum aestivum* L.) has been one of the most studied plants for evaluation of response to climate change. Wheat as one of the most important staple food crops, is grown on about 225 million ha worldwide from the equator to latitudes of 60 ° N and 44 ° S and at altitudes ranging from sea level to more than 3,000 m. Approximately 90 % area of Iran is considered as arid and semiarid and rainfed wheat is the dominant crop in local cropping patterns (Bannayan et al. 2010). Climate changes may affect overall wheat production by altering the production area, yields or both. About 4.2 million ha of land in Iran is under rainfed farming (Bannayan et al. 2010). In addition, annual average production of rainfed wheat is about 1,073 (kg/ha$^{-1}$) in Iran (Bannayan et al. 2011a). Khorasan province with 9 % land under wheat cultivation and 8.3 % production carry the first and third ranks across the country, respectively (Bannayan et al. 2010).

IPCM4 and HadCM3 general circulation models were developed by Institute Pierre Simon Laplace, France and United Kingdom Met Office Hadley Center (Semenov and Stratonovitch 2010). The United Nations Intergovernmental Panel on Climate before (IPCC) has defined standard greenhouse gas emission scenarios for use in the examination of projected climate change based on various socioeconomic, technological and energy use factors (IPCC 2007). The Special Report on Emissions Scenarios (SRES)-A2 scenario indicated a very heterogeneous world conditions with high population growth rate, slight economic development and slow technological change (Prudhomme et al. 2010). The Special Report on Emissions Scenarios (SRES)-B1 defines a convergent world with a global population that peaks in mid-century and rapid changes in economic structures towards a service and information economy (Wetterhall et al. 2009). The Special Report on Emissions Scenarios (SRES)-A1B scenario describes future world with very sharp economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies (Hanafin et al. 2010). This scenario assumes a balance across all sources of technology (fossil intensive and non-fossil energy source) (Prudhomme et al. 2010). Koocheki et al. (2006) reported 21 % to 41 % decrease of rainfed wheat yield under future climate conditions. Their projection of wheat yield was only based on one scenario and one GCM model United Kingdom Meteorological Office (UKMO) without considering the uncertainty of climate change. Predicting soybean yield under future climate conditions with HadCM2 and Canadian Global Climate Model (CGCM2) indicated significant increase of growing season length and water deficit during this period in eastern Canada (Pearson et al. 2008). Abraha and Savage (2006) showed a sharp increase in minimum and maximum temperature and precipitation rate by climate change processes in South Africa, and resulted that maize (*Zea mays* L.) grain yields would be much more affected by

changes in mean air temperature than by precipitation. Temperature rise has been reported for future climate in Mediterranean area by different scenarios and GCM models as well (Herting and Jacobeit 2008). Laux et al. (2010) projected higher temperature during 2020 to 2080 in dry regions of Cameroon and resulted that future climate will decrease grain yield of maize and groundnut (*Arachis hypogaea L.*) however, higher carbon dioxide ($CO_2$) concentration may partly mitigate this loss. Guo et al. (2010) reported that under A2A, B2A and A1B scenarios along with climate projections by HadCM3 global climate model, average wheat and maize yield would respectively increase by 9.8 % and 3.2 % without $CO_2$ fertilization in the North China Plain. Liu et al. (2010) showed 2 °C to 5 °C increase in temperature and 15 %–30 % increase in precipitation rate in China. They concluded that higher temperature showed more impact than $CO_2$ concentration on wheat yield and future temperature level will reduce the crop yield.

This study focuses on assessing climate change impact on rainfed wheat production under climate change conditions by performing Cropping System Model- Crop-Environment Resource Synthesis (CSM-CERES) wheat model along with two different general circulation models (IPCM4 and HadCM3) and three different scenarios (A1B, A2 and B1) in Khorasan province as a semi-arid region of Iran.

## 2 Methods

### 2.1 Study area

Khorasan province covers an area of about 248,000 $km^2$ in northeast of Iran (Fig. 1). This extensive area is inhibited by more than 6 million people and agriculture plays a vital economic role. Khorasan climate is highly variable (Bannayan et al. 2011a), however rainfed farming is the most commonly cultivation pattern in this area due to semiarid condition. Mashhad, Birjand, Bojnourd and Sabzevar are dominant agricultural regions in Khorasan. These regions situated between 32 °–37 ° N latitude. Climatic characteristics of study region are presented in Table 1. Average precipitation across the Khorasan province during last 40 years was 222 mm and varies from about 169 mm at the southern area (Birjand) to 269 mm in northern area (Bojnourd). Generally, rainfall is rare from July to September (IMO 2009). Rainfed wheat yield in study region varies from year to year, largely as the result of high variability in precipitation (Bannayan et al. 2011a). Total wheat production area is more than 353.000 $ha/yr^{-1}$ in study region (Khorasan Ministry of Agricultural statistics 2008). Soil texture of all study locations except Mashhad (clay loam) is loam soil and soil bulk density ($gr/cm^{-3}$) varies between 1.30 and 1.35 $gr/cm^{-3}$ (Bannayan et al. 2011b).

### 2.2 Data sets

Daily climate data including, maximum and minimum temperature (°C) and precipitation (mm) were obtained for the period of 1961–1990 of Mashhad, Birjand, Bojnourd and Sabzevar climatological stations. Two GCM models, and three scenarios employed in this study. The GCM models included the Institute Pierre Simon Laplace (IPCM4) (Semenov and Stratonovitch 2010) and United Kingdom Met Office Hadley Center (HadCM3) (Mitchell et al. 1995) and scenarios were SRA1B, SRES-A2 and SRES-B1. HadCM3 and IPCM4 are coupled atmosphere–ocean GCMs that described by Gordon et al. (2000) and Hourdin et al. (2006) respectively. Both GCMs resolved at a spatial resolution of 2.5 ° latitude by 3.75 ° longitude.

LARS-WG is a stochastic weather generator based on the series approach (Semenov and Stratonovitch 2010). LARS-WG produces synthetic daily time series of maximum and

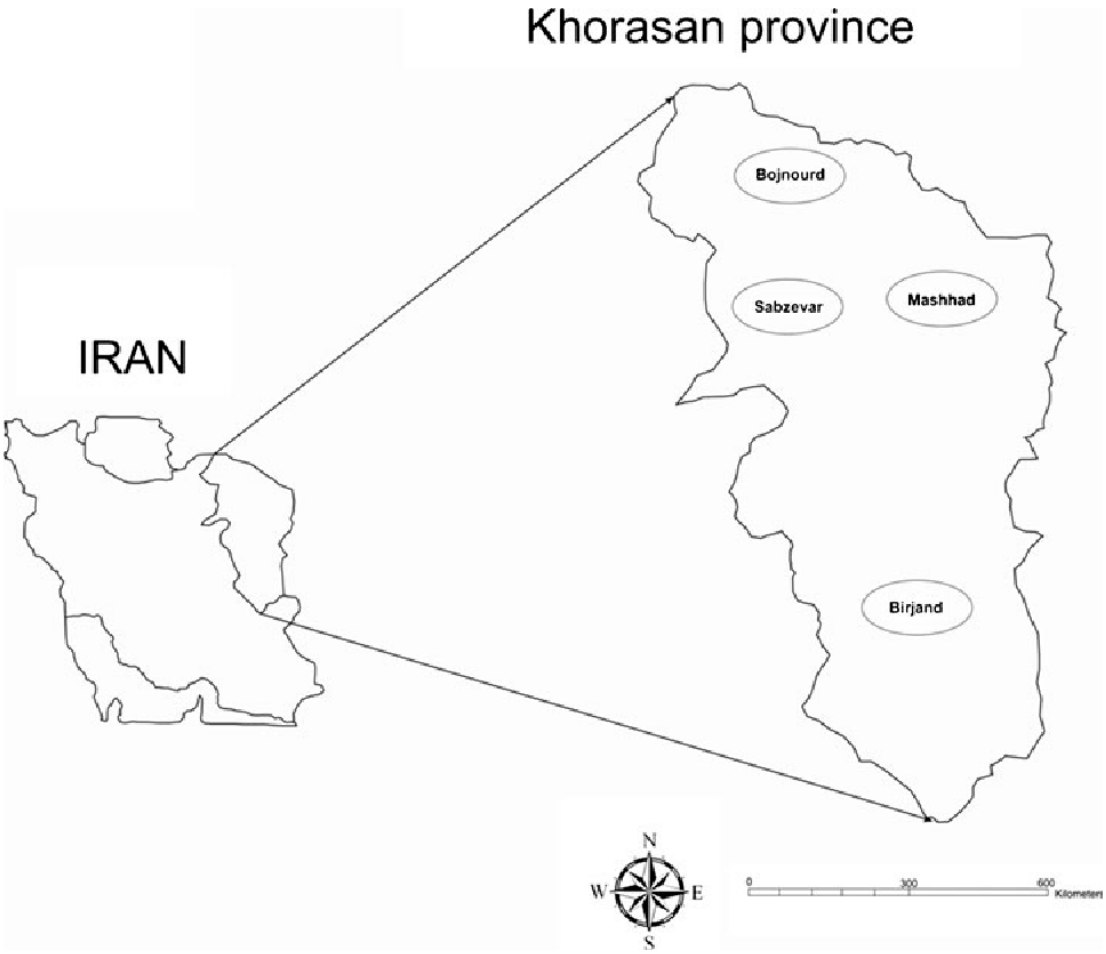


**Fig. 1** Study locations in Khorsan Province, Iran

minimum temperature, precipitation and solar radiation. LARS-WG applies observed daily weather data for a given site to compute a set of parameters for probability distributions of weather variables as well as correlations between them (Semenov and Brooks 1999). In this study, this model was used to produce daily climate variables as one stochastic set of data for a growing season for each projection period which is required for crop growth simulation model. This 1 year data included maximum and minimum temperature and precipitation of Khorasan province for four projection time (1961–1990 (baseline), 2010–2039, 2040–2069,

**Table 1** Climatic features of study sites Khorsan Province, Iran

| Location | LA | LN | Altitude (m) | Annual precipitation (mm) | Tmax (°C) | Tmin (°C) | Seasonal mean temperature (°C) | Sunshine hours |
|---|---|---|---|---|---|---|---|---|
| Mashhad | 36.16 | 59.38 | 999 | 256.4 | 31.1 | 15 | 23.4 | 329.8 |
| Sabzevar | 36.12 | 57.43 | 977.6 | 192.1 | 34.5 | 19.7 | 27.7 | 323.7 |
| Bojnourd | 37.28 | 57.19 | 1,091 | 269.2 | 29.2 | 14.5 | 22.2 | 300.1 |
| Birjand | 32.52 | 59.12 | 1,491 | 169.6 | 33.3 | 16 | 25.6 | 333.3 |

*LA* latitude; *LN* longitude; *Tmax* mean of maximum temperature in growth season; *Tmin* mean of minimum temperature in growth season; *Sunshine hours* sunshine hours in growth season

and 2070–2099). Based on this method, climate change data which imbedded in GCMs, was employed for adjustment of the parameters of the LARS-WG which had previously been calibrated for study locations by observed daily climate data and then site-specific climate projections generated (Semenov and Barrow 1997). In addition, uncertainty was evaluated by Wilcoxon rank sum method as a non-parametric test. This test is an alternative to the two-sample *t*-test which is based solely on the order in which the observations from the two samples fall (Conover 1980).

Two years field experiment data in two various locations was used for crop model validation and 1 year separate experiment data was employed for model calibration. Of the two experiments used for validation the first one was conducted in Shirvan Dryland Agricultural Research Institute which located 50 Km away from Mashhad site. This experiment investigated the impacts of different planting densities on yield and yield components of rainfed wheat (Sharifi and Rahimian Mashhadi 2001). Five levels of planting densities (200, 250, 300, 350 and 400 plant per square meter) and two levels of irrigation (rainfed and supplement irrigation) within a split plot factorial experiment based on a randomized complete block design with three replications was considered in the experiment. In the second experiment (1998) the impact of different levels of phosphorus and seed rate on yield of rainfed wheat (Koocheki and Azemzade 1999) was investigated. In both experiments, Sardari wheat cultivar was cultivated. The simulation model options were set according to weather, soil and treatments which employed on these two experiments. Fluctuations of dry weight and leaf area index (LAI) detected by 10 days period samplings after tillering stage of wheat in both experiments.

### 2.3 Model calibration

The Decision Support System for Agrotechnology Transfer (DSSAT) comprises of six models for simulating the growth of 16 crops of economic importance (Jones et al. 2003). The model has demonstrated high reliability under different climates, soil, and management conditions (Bannayan et al. 2003). The CSM-CERES Wheat model is one of the most popular and highly reliable wheat models (Rinaldi 2004) and has been evaluated in many sites across the world and the results indicated its capability to simulate grain yields under different climatic conditions (Pecetti and Hollington 1997).

Sardari cultivar is one of the commonly used varieties of rainfed wheat in Iran (Khorasan Ministry of Agricultural statistics 2008). The crop model was calibrated by a separate experiment which was conducted at experiment station of the College of Agriculture, Ferdowsi University of Mashhad (latitude: 36 °15′ N, longitude: 59 °28′ E: 928 m) in the central part of Khorasan province. In this experiment the effects of planting density and different cultivars of rainfed wheat in Khorasan province situation were investigated. Three density treatment (250, 300 and 350 plant per square meter) and two rainfed wheat cultivars (Sardari and Sabalan) within factorial experiment based on randomized complete block design with three replications was conduced (Sharifi and Rahimian Mashhadi 2001). Common planting date of rainfed wheat in the study area is about early November in all study locations. Some of the measured factors such as, grain yield, biological yield, leaf area index in different growth stages, plant height, tiller numbers, 1,000 seed weight, days to heading and days to maturity, harvest index and spikelet number in ground $m^2$ were provided for the model as observed data. Genetic coefficients of Sardari cultivar are represented in Table 2.

**Table 2** Genetic coefficients of Sardari wheat cultivar

| P1V | P1D | P5 | G1 | G2 | G3 | PHINT |
|---|---|---|---|---|---|---|
| 1 | 40 | 450 | 13 | 41 | 1.5 | 60 |

*P1V* days at optimum vernalizing temperature required to complete vernalization, *P1D* percentage reduction in development rate in a photoperiod 10 h shorter than the threshold relative to that at the threshold. *P5* grain filling (excluding lag) phase duration (°C.d), *G1* kernel number per unit canopy weight at anthesis, *G2* standard kernel size under optimum conditions (mg), *G3* standard, non-stressed dry weight (total, including grain) of a single tiller at maturity (g), *PHINT* interval between successive leaf tip appearances (°C.d)

### 2.4 Model validation

Several criteria were calculated to quantify the difference between simulated and observed data. The root mean-squared error (RMSE) is computed to measure the coincidence between measured and simulated values, while mean deviation (RMD) is calculated to evaluate systematic bias of the model. Model efficiency (EF) is calculated to estimate model performance in relation to the observed mean (Nash and Sutcliffe 1970). Moreover, linear regression detected between simulations and observations to evaluate model performance and correlation coefficient ($R^2$) determined for each simulation.

$$RMSE = \frac{100}{\overline{O}}\sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$$

$$RMD = \frac{100}{\overline{O}}\sum_{i=1}^{n}\frac{P_i - O_i}{n}$$

$$EF = 1 - \frac{\sum_{i-1}^{n}(P_i - O_i)^2}{\sum_{i-1}^{n}\left(\overline{O} - O_i\right)^2}$$

Where $P$ and $O$ are simulated and observed data, respectively, in addition $\overline{O}$ is the mean of observed data and $n$ is the number of observations. The RMSE illustrated the model's prediction error by heavily weighting high errors, whilst the RMD use same weights for all errors, which tends to smooth out discrepancies between simulated and observed data. EF indicated the efficiency of the model and can have positive or negative values (Huang et al. 2009; Bannayan and Hoogenboom 2008).

## 3 Results

### 3.1 Model evaluation

#### *3.1.1 Climate model*

The precise estimate of weather variables such as maximum and minimum temperature and precipitation in baseline period may show accuracy of downscaling models in climate

change researches (Viglizzo et al. 1997). Climate downscaling model indicated high accuracy projection of maximum and minimum temperature of Mashhad (Fig. 2a and b) and Bojnourd (Fig. 2d and e) locations. Similar results obtained with significant accuracy for Birjand (Fig. 2g and h) and Sabzevar (Fig. 2j and k) locations. All predictions of maximum and minimum temperature showed RMSE values of less than 2.0 % except minimum temperature in Sabzevar location (RMSE=3 %). Precipitation precision was less than temperature especially in Mashhad (Fig. 2f) and Bojnourd (Fig. 2c). However, the downscaling model showed high accuracy for precipitation in Birjand (Fig. 2i) and Sabzevar (Fig. 2l) locations with RMSE values of less than 10.0 %.

Wilcoxon rank-sum test showed insignificant for all months at 5 % significance level, except Sep and Oct months for Sabzevar and Birjand for minimum and maximum temperatures, respectively (Table 4). In addition, Bojnourd (Sep), Birjand (Mar) and Sabzevar (Apr) indicated significant error in precipitation simulation (Table 4).

### *3.1.2 Crop model*

Crop model evaluation results showed an adequate accuracy of grain and biomass simulation (Table 3) and a significant correlation obtained between observed and simulated grain yield and biomass (Table 3). Maximum leaf are index was simulated within±8 % of the measured one (RMSE=8.1 %). Simulated and observed maximum leaf area index showed a ($R^2$=0.94) significant correlation (Table 3). Simulated values of leaf area index especially under rainfed situations were relatively higher than the observed ones (Teruel et al. 1997; Xue et al. 2003).

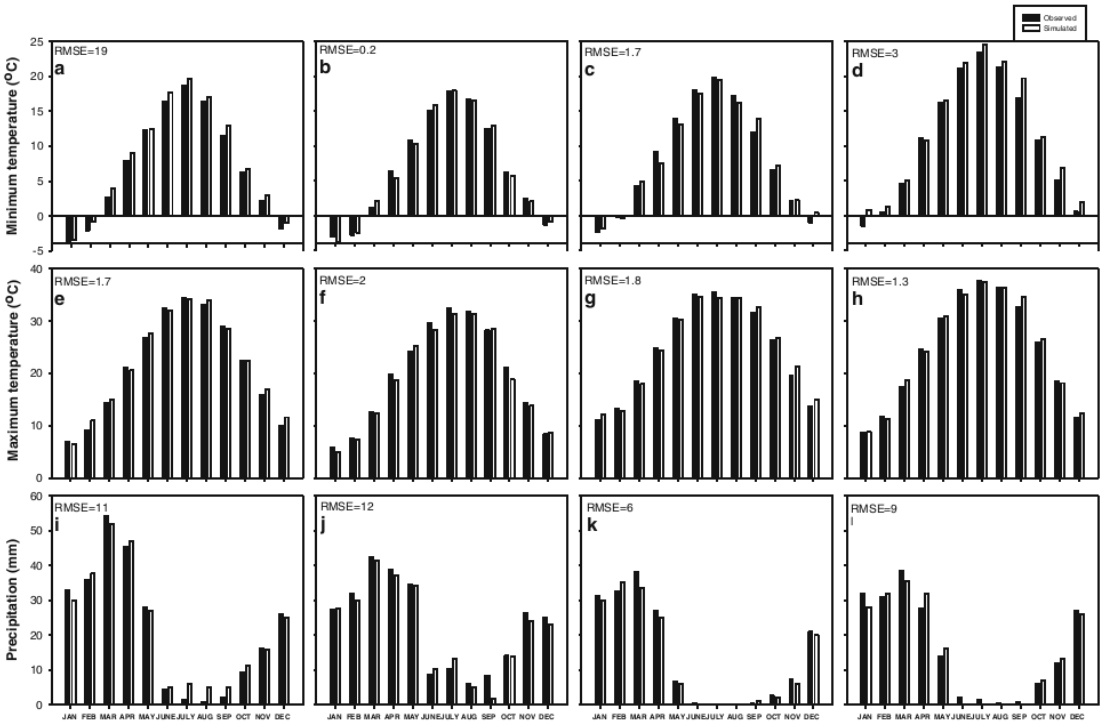


**Fig. 2** Comparison of simulated and observed climatic parameters (RMSE%). Minimum temperature (°C) for Mashhad (**a**), Bojnourd (**b**), Birjand (**c**), Sabzevar (**d**), maximum temperature (°C) for Mashhad (**e**), Bojnourd (**f**), Birjand (**g**), Sabzevar (**h**), and precipitation (mm) Mashhad (**i**), Bojnourd (**j**), Birjand (**k**), Sabzevar (**l**)

**Table 3** Comparison of simulated and observed grain and biological yield and maximum leaf area index by root mean-squared error (RMSE (%)), root mean deviation (RMD (%)), model efficiency (EF) and $R^2$ values

| Parameters | RMSE (%) | RMD (%) | EF | $R^2$ |
|---|---|---|---|---|
| Grain yield | 5.31 | 4.12 | 0.10 | 0.88 |
| Crop biomass | 4.81 | 4.5 | −4.7 | 0.51 |
| Maximum leaf area index | 8.10 | 7.14 | 0.19 | 0.94 |

## 3.2 Precipitation during growth period

Precipitation is among the most important factors which determine rainfed crops yield in arid and semi arid regions of the world (Lopez-Castaneda and Richards 1994). A sharp decrease of precipitation within growth period was obtained for Mashhad location using both GCM models under A1B and A2 scenarios in all projected time periods (Fig. 3a and b). However, nearly all locations (except Bojnourd and Sabzever locations using HadCM3 model) under B1 scenario indicated a slight increase of precipitation compared to baseline time period in 2070–2099. Projections indicated dramatic reduction of precipitation compared to baseline by both GCM models, under all scenarios and time periods in Bojnourd. A1B scenario showed highest decrease of precipitation for all time periods (Fig. 3c and d). Precipitation in Birjand location displayed slow fall in 2010–2039 period by HadCM3 and IPCM3 models under all scenarios (Fig. 3e and f), however for 2070–2099 illustrated a moderate rise (Fig. 3e and f). Sabzevar location represented steady slump of precipitation under both GCM models and scenarios especially in 2010–2039 period (Fig. 3g and h).

## 3.3 Wheat yield

### *3.3.1 B1 scenario*

Our results showed great difference in grain yield of wheat between various locations in Khorasan province using different General Circulation Models and climatic scenarios. B1 scenario considers the world conditions more optimistic. Wheat grain yields showed no change or gentle drop (−10 % to −18 %) trend in all study locations except Bojnourd using both GCM models in 2010–2039 period (Fig. 4a and b). Wheat yield increased slowly (+9 %) in Bojnourd location in 2010–2039 period using HadCM3 model (Fig. 4a). B1 scenario indicated slight increase of wheat yield in Sabzevar and Birjand locations (+10 %) using HadCM3 model in 2040–2069 period (Fig. 4c). Other locations showed marginal fall (−10 % to 20 %) of wheat yield under both scenarios except Bojnourd location using IPCM4 model which illustrated unchanged trend in 2040–2069 period (Fig. 4c and d). Yield trend showed considerable rise (7 % to 18 %) in all study locations using HadCM3 model in 2070–2099 period (Fig. 4e). IPCM4 model indicated no change trend in Mashhad and Sabzevar locations, however, Bojnourd location showed negligible surge in wheat yield in 2070–2099 period (Fig. 4f).

### *3.3.2 A1B scenario*

Wheat grain yield showed dramatic drop in Mashhad (−30 %), Bojnourd (−15 %) and Birjand (28 %) locations using both HadCM3 and IPCM4 models under A1B scenario in 2010–2039 period (Fig. 5a and b). however, wheat yield remained unchanged in Sabzevar

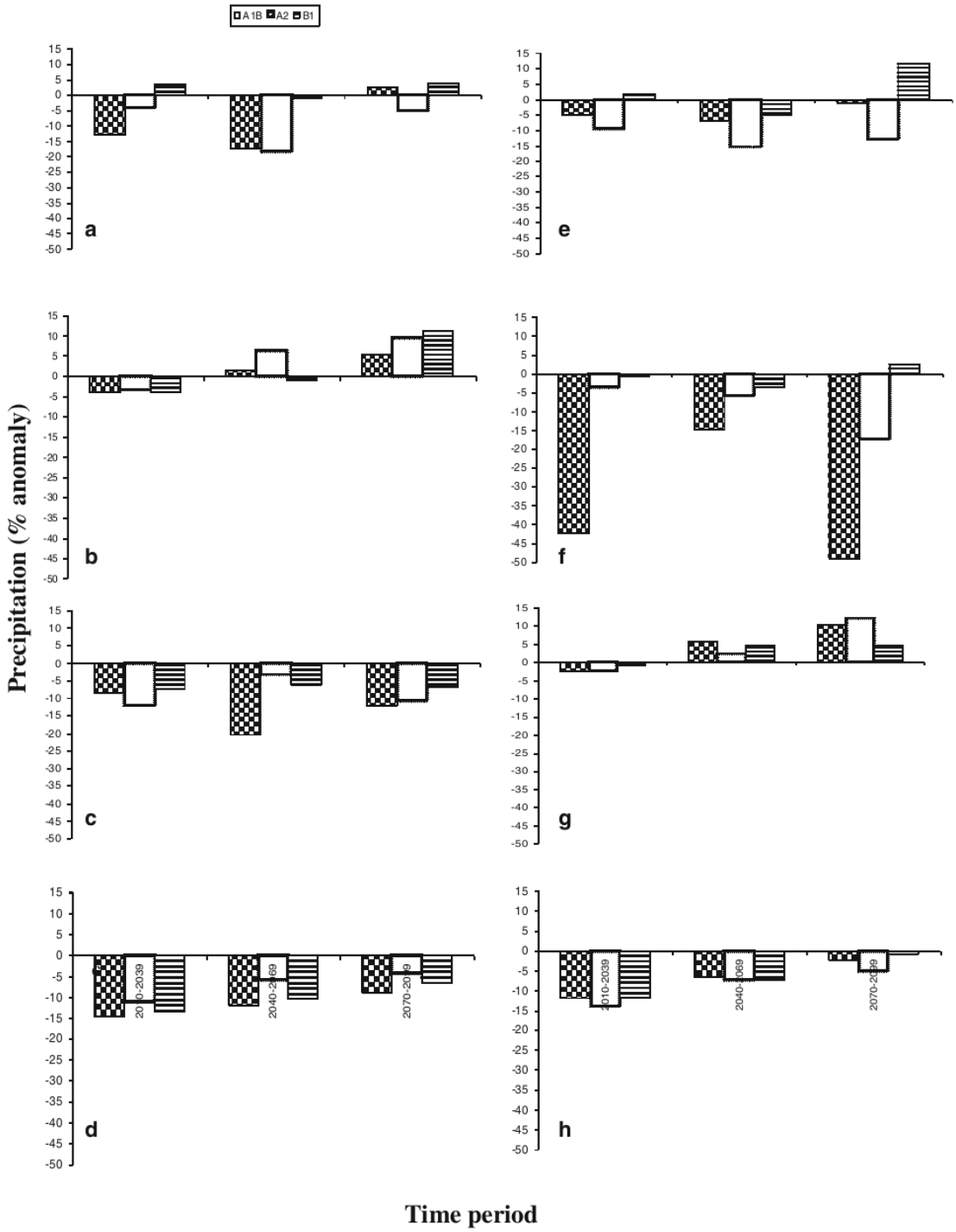


**Fig. 3** Percentage of precipitation anomaly (%) during growth period of wheat under climate change conditions compared to baseline. HadCM3 outputs for Mashhad (**a**), Bojnourd (**b**), Birjand (**c**), Sabzevar (**d**), IPCM4 outputs for Mashhad (**e**), Bojnourd (**f**), Birjand (**g**), Sabzevar (**h**) locations

location in 2010–2039 period compared to base period under HadCM3 model (Fig. 5a). Wheat yield fluctuation illustrated sharp decrease in Mashhad (both GCM models) and Bojnourd (HadCM3 model) in 2040–2069 period (Fig. 5c and d). Attainable yield indicated moderate rise (+10 and 15 %) in Birjand and Sabzevar locations respectively under HadCM3 model in 2040–2069 period (Fig. 5c). Yield trend under HadCM3 model represented gradual

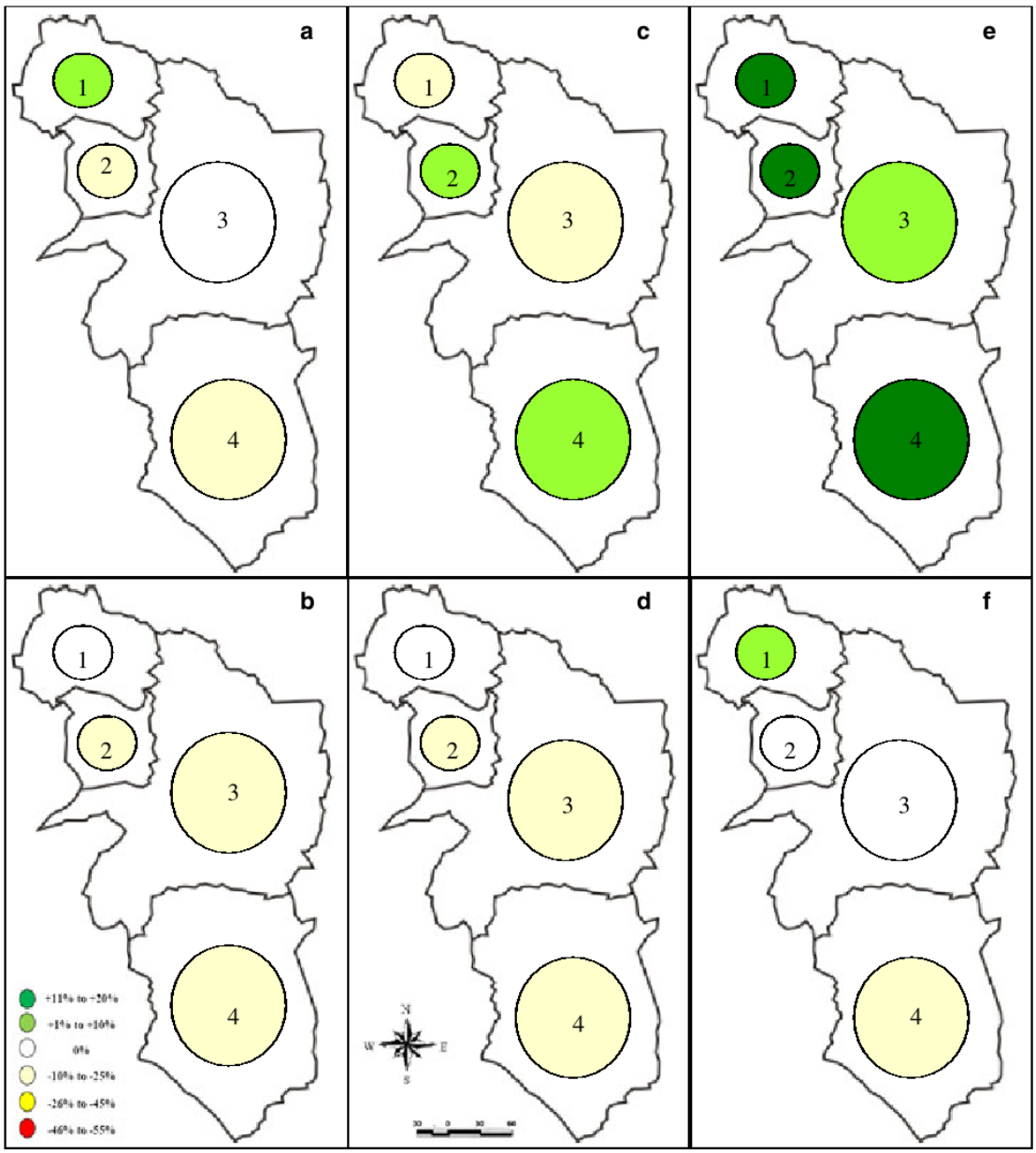


**Fig. 4** Percentage of wheat grain yield change in future climatic conditions compared to baseline which resulted by HadCM3 model in different time periods (**a** (2010–2039), **c** (2040–2069) and **e** (2070–2099)) and IPCM4 model (**b** (2010–2039), **d** (2040–2069) and **f** (2070–2099)) for various locations in Khorasan province under B1 scenario. (1, Bojnourd; 2, Sabzevar; 3, Mashhad; 4, Birjand)

increase in Birjand (+5 %) and Sabzevar (+10 %) locations (Fig. 5e) but IPCM4 model did not show any yield change in these locations in 2070–2099 period (Fig. 5f). HadCM3 resulted in highest decrease of wheat yield (−50 %) under A1B scenario for Bojnourd location (Fig. 5e). Sabzevar and Mashhad yield trend reached a plateau using HadCM3 and IPCM4 models respectively (Fig. 5e and f).

### *3.3.3 A2 scenario*

In comparison with baseline period, lowest wheat grain yield obtained under A2 scenario (−55 %) in Bojnourd (using HadCM3) and Mashhad (using IPCM4) in 2010–2039 (Fig. 6a

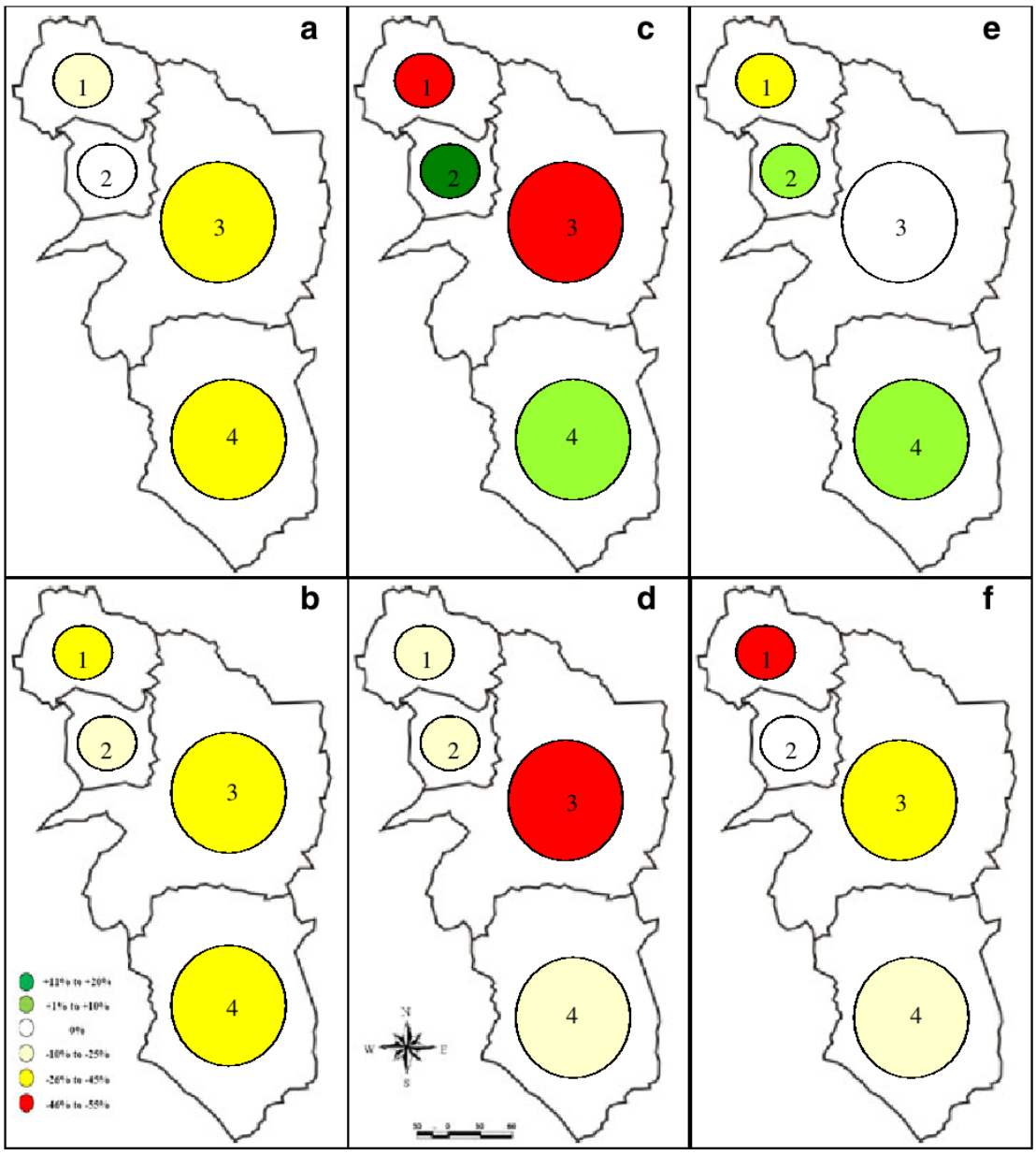


**Fig. 5** Percentage of wheat grain yield change in future climatic conditions compared to baseline which resulted by HadCM3 model in different time periods (**a** (2010–2039), **c** (2040–2069) and **e** (2070–2099)) and IPCM4 model (**b** (2010–2039), **d** (2040–2069) and **f** (2070–2099)) for various locations in Khorasan province under A1B scenario. (1, Bojnourd; 2, Sabzevar; 3, Mashhad; 4, Birjand)

and b). Other locations represented modest decrease of yield in 2010–2039 period (Fig. 6a and b). Significant decreasing trend in Mashhad and Bojnourd locations was obtained under A2 scenario and using HadCM3 model however Sabzevar and Birjand locations indicated little change in 2040–2069 compared to baseline period (Fig. 6c). There was modest negative trend (−10 % to −25 %) of wheat yield using IPCM4 model under A2 scenario across all locations, except for Mashhad location (−26 % to −45 %) in 2040–2069 period (Fig. 6d). Mashhad (−10 %) and Bojnourd (−15 %) locations indicated negligible decline of wheat yield using HadCM3 model in 2070–2099 period (Fig. 6e), but this decrease was more (−29 % to −40 %) when IPCM4 model was used (Fig. 6f). Wheat yield showed an increasing trend in Sabzevar and Birjand locations under A2 scenario using HadCM3 model

for 2070–2099 period (Fig. 6e), but projections by IPCM4 model showed a negative trend (Fig. 6f).

### 3.4 Crop evapotranspiration ($ET_{c.}$)

Accurate prediction of a given crop evapotranspiration (ET) within growth period is essential key element in agricultural water management especially in arid and semi-arid areas such as Iran (Dinpashoh 2006). Mashhad and Bojnourd locations showed slight fall in $ET_{c.}$ using HadCM3 model in all time periods and scenarios except under B1 in 2070–2099 period (Table 5). However, $ET_{c.}$ fluctuations represented gentle decreasing trend based on

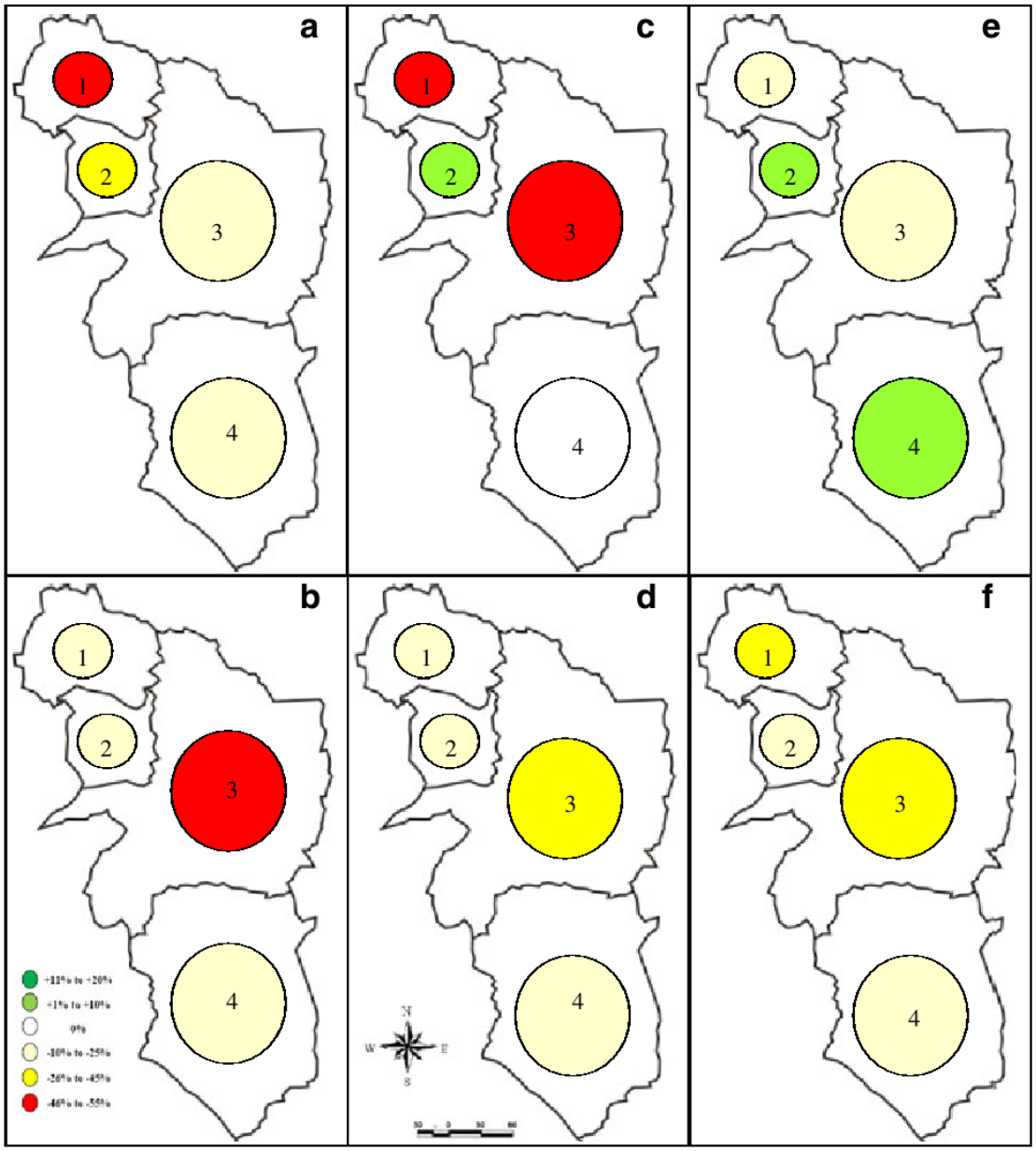


**Fig. 6** Percentage of wheat grain yield change in future climatic conditions compared to baseline which resulted by HadCM3 model in different periods (**a** (2010–2039), **c** (2040–2069) and e (2070–2099)) and IPCM4 model (**b** (2010–2039), **d** (2040–2069) and **f** (2070–2099)) for various locations in Khorasan province under A2 scenario. (1, Bojnourd; 2, Sabzevar; 3, Mashhad; 4, Birjand)

IPCM4 model under different scenarios and time periods in Mashhad and Bojnourd compared to baseline (Table 4). B1 scenario indicated lowest fluctuations between different scenarios. $ET_{c.}$ within growth period in Birjand and Sabzevar locations showed relatively stable trend using both climate models and scenarios in comparison with baseline (Table 5).

### 3.5 Trend detection

Precipitation and evapotranspiration as the most important parameters for determination of rainfed crops yields in arid and semi arid regions are tied together (Katerji et al. 1998). We found significant positive correlation between simulated grain yield with precipitation ($r$= $0.87^{**}$) (Fig. 6a) and grain yield and evapotranspiration during growth period ($r$=$0.78^{**}$) (Fig. 6b). Furthermore, noticeable positive trend detected between ET and precipitation in growth period ($r$=$0.91^{**}$) (Fig. 6c).

## 4 Discussion

The results of this study showed that future climate will directly influence crop grain yield especially in arid and semi arid regions. Mashhad and Bojnourd locations as the most important cereal cultivation regions across the Khorasan province showed higher decrease of the rainfed wheat grain yield than Birjand and Sabzevar locations compared to baseline (Figs. 4, 5 and 6). However, all stations showed significant decrease of the grain yield under all scenarios in first time period (2010–2039). It seems precipitation fluctuations within the growth period (generally negative trend) and different scenarios are the main reason of yield decline in future climate. For instance, Bojnourd location showed more than 40 % decline in precipitation under IPCM4 in 2010–2039 period (Fig. 3d). This is well documented that increasing the drought stress and higher temperatures tend to reduce the rainfed wheat grain yield owing to the fact that declining water availability and high temperatures declines the

**Table 4** Test results (p-values) of the Wilcoxon rank sum test for the difference of means of observed and downscaled daily maximum and minimum temperature and precipitation at 95 % confidence level

| | Mashhad | | | Bojnourd | | | Birjand | | | Sabzevar | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tmin | Tmax | Pre | Tmin | Tmax | Pre | Tmin | Tmax | Pre | Tmin | Tmax | Pre |
| JAN | 0.532 | 0.473 | 0.221 | 0.542 | 0.482 | 0.531 | 0.352 | 0.313 | 0.345 | 0.058 | 0.204 | 0.115 |
| FEB | 0.171 | 0.152 | 0.167 | 0.344 | 0.375 | 0.266 | 0.245 | 0.218 | 0.155 | 0.254 | 0.226 | 0.249 |
| MAR | 0.215 | 0.191 | 0.287 | 0.267 | 0.291 | 0.437 | 0.369 | 0.328 | 0.047 | 0.157 | 0.140 | 0.210 |
| APR | 0.144 | 0.158 | 0.238 | 0.183 | 0.199 | 0.299 | 0.163 | 0.145 | 0.218 | 0.148 | 0.132 | 0.036 |
| MAY | 0.342 | 0.376 | 0.342 | 0.589 | 0.524 | 0.477 | 0.456 | 0.406 | 0.369 | 0.351 | 0.312 | 0.284 |
| JUN | 0.098 | 0.108 | 0.198 | 0.254 | 0.226 | 0.206 | 0.562 | 0.500 | 0.550 | 0.542 | 0.482 | 0.531 |
| JUL | 0.157 | 0.173 | 0.157 | 0.441 | 0.481 | 0.529 | 0.371 | 0.330 | 0.363 | 0.153 | 0.136 | 0.150 |
| AUG | 0.357 | 0.318 | 0.350 | 0.365 | 0.325 | 0.357 | 0.261 | 0.232 | 0.256 | 0.473 | 0.421 | 0.463 |
| SEP | 0.294 | 0.262 | 0.523 | 0.148 | 0.132 | 0.012 | 0.114 | 0.101 | 0.112 | 0.042 | 0.061 | 0.067 |
| OCT | 0.421 | 0.459 | 0.305 | 0.387 | 0.023 | 0.161 | 0.423 | 0.402 | 0.603 | 0.254 | 0.277 | 0.305 |
| NOV | 0.573 | 0.510 | 0.161 | 0.251 | 0.223 | 0.246 | 0.242 | 0.230 | 0.253 | 0.157 | 0.140 | 0.154 |
| DEC | 0.722 | 0.143 | 0.572 | 0.392 | 0.349 | 0.244 | 0.089 | 0.214 | 0.363 | 0.243 | 0.216 | 0.238 |

*Tmin* minimum temperature, *Tmax* maximum temperature, *Pre* precipitation

**Table 5** Percentage of changes in Evapotranspiration (ET) during growth period of wheat under climate change conditions compared to baseline

| GCM model | Scenario | Periods | Mashhad | Bojnourd | Birjand | Sabzevar |
|---|---|---|---|---|---|---|
| HadCM3 | A1B | 2010–2039 | −2 | −12 | −5 | −7 |
| | | 2040–2069 | −3 | −18 | 2 | −5 |
| | | 2070–2099 | −2 | −15 | 1 | −1 |
| | A2 | 2010–2039 | −13 | −20 | −5 | −5 |
| | | 2040–2069 | −6 | −10 | −2 | 1 |
| | | 2070–2099 | −1 | −13 | 0 | −3 |
| | B1 | 2010–2039 | −2 | −8 | −6 | −4 |
| | | 2040–2069 | −18 | −5 | −5 | −3 |
| | | 2070–2099 | 30 | −6 | 3 | 1 |
| IPCM4 | A1B | 2010–2039 | 1 | −18 | −5 | −3 |
| | | 2040–2069 | −5 | −7 | −3 | −6 |
| | | 2070–2099 | 2 | −19 | 3 | 0 |
| | A2 | 2010–2039 | −9 | −6 | −7 | −5 |
| | | 2040–2069 | −11 | −7 | −2 | −5 |
| | | 2070–2099 | −6 | −14 | 2 | −1 |
| | B1 | 2010–2039 | 6 | −4 | −5 | −5 |
| | | 2040–2069 | −3 | −8 | 2 | −3 |
| | | 2070–2099 | 9 | 1 | −1 | −1 |

length of the growing period thus less radiation interception which results in lower biomass production (Eitzinger et al. 2003; Ludwig and Asseng 2006). Tubiello et al. (2002) predicted −4 % to −30 % of decrease in rainfed wheat yield (winter wheat) under climate change conditions (2090) across different parts of USA. Significant correlation between rainfall within growth period and grain yield showed strong relationship between them (Fig. 7a). Precipitation is a key climate parameter in agriculture of Iran owing to the fact that Iran located in arid and semi arid parts of world and rainfed farming of cereals is the most important agricultural business in this country (Tavakkoli and Oweis 2004). Generally, climate change impact on crop evapotranspiration during the growth period compared to baseline was negative but this effect was not significant (Table 4). There was no significant deference between HadCM3 and IPCM4 models in projecting the grain yield of wheat but various scenarios resulted in different yield. In general, B1 scenario represented highest yield stability across all stations and time periods. A1B and A2 scenarios showed dramatically lower yield and precipitation compared to baseline across all stations and time periods. However, slope of this negative trend was lower in 2070–2099 period compared to other future time periods. Central part of study region (Mashhad) showed highest decrease of wheat grain yield under climate change but there was no specific trend among different GCM models and scenarios. A2 scenario is based on more than 3 °C increase in mean temperature from 2000 to 2100 (IPCC 2001). However, B1 emission scenario describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, and less than 2 °C change in mean temperature during next 100 years (IPCC 2001). In addition, the SRES A1B scenario illustrates a future world with rapid economic growth and global population. Emissions peak in midcentury and

decline there after since of rapid introduction of more capable technologies, and balanced usage between fossil fuels and other energy sources (Tagaris et al. 2007).

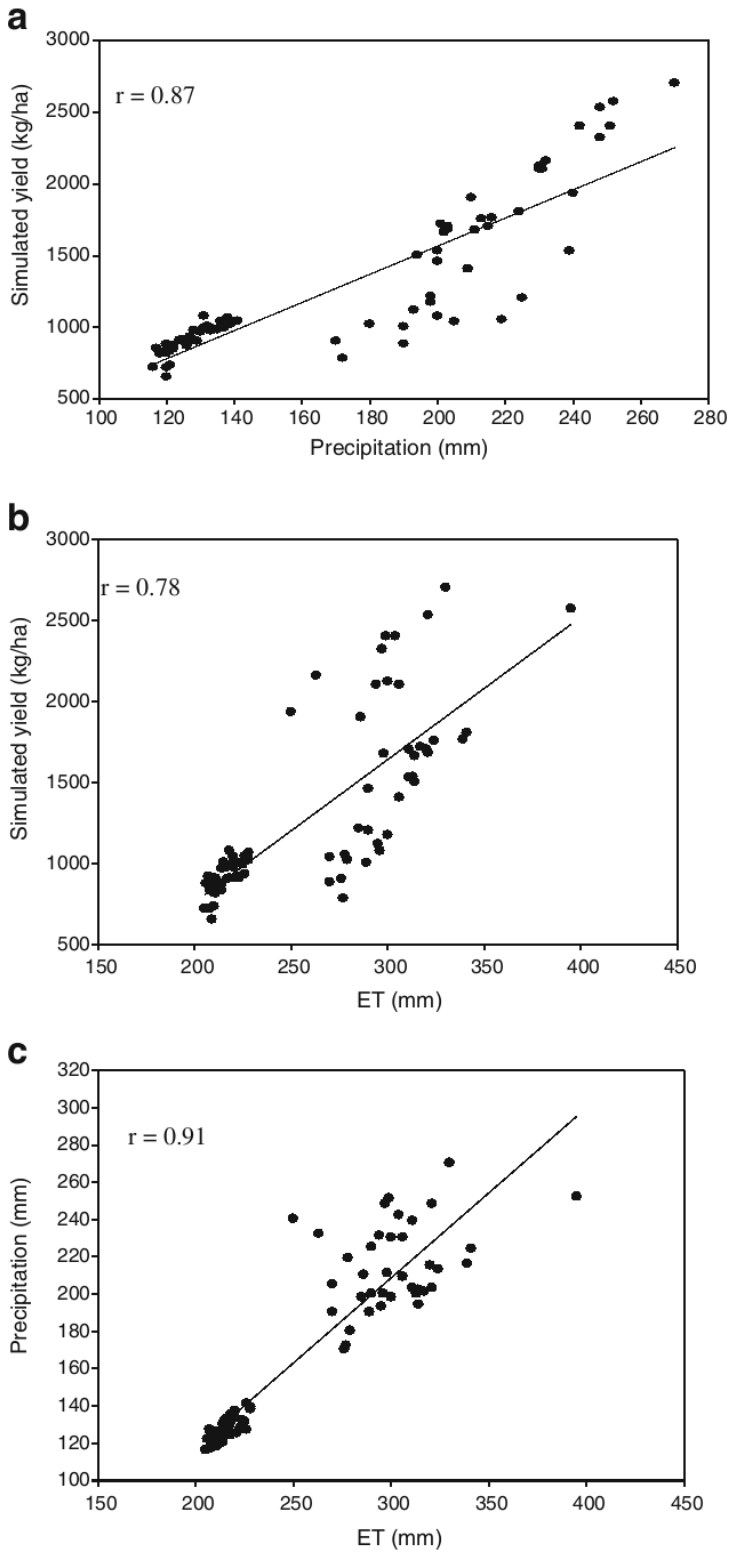


**Fig. 7** Relationship between simulated wheat grain yield (kg/ha$^{-1}$) and precipitation (mm) (**a**), evapotranspiration (mm) (**b**) and between precipitation (mm) and evapotranspiration (mm) (**c**)

In conclusion, our results showed that rainfed wheat production in semi-arid region of Khorasan province may gradually decline during next 80 years with considering precipitation deficiency during wheat growth period. Therefore, we strongly recommended to restructure cropping patterns and plan mitigation strategies such as change of sowing time, planting densities and employ acclimated rainfed wheat cultivars to decline possible deleterious impacts of climate change.

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