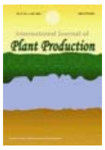

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Regional climate change scenarios and their impacts on water requirements for wheat production in Iran

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Abstract

We simulate the effect of climate change on water requirements of cold season wheat in various climatic zones of Iran. The research considers both observed climate (temperature and precipitation) changes during recent decades (1960-2009) based on instrumental records and projected future changes to 2100 based on the MAGICC/SCENGEN 5.3 compound model. 20 General Circulation models are used based on a single scenario known as P50, which is the average of SRES or emission scenarios. Results indicate that whilst winter precipitation has marginally increased across the country as a whole, a significant decline in mean spring precipitation is recorded between 1960 and 2009. However, considerable variability in trends is measured across various climatic regions of Iran. Mean annual temperature / rainfall changes in the various climate zones of Iran for the period 1960-2009 follow: +0.1 °C / decade / +0.43 mm / decade in arid regions, -0.1 °C / decade / -1.7 mm / decade in semi-arid regions, +0.1 °C / decade / -1.33 mm / decade in Mediterranean / semi-humid regions and -0.01 °C / decade / -0.04 mm / decade in humid / hyper humid regions. Temperature projections to 2100 indicate an overall temperature rise of ca. 4.25 °C relative to that for 1961-1990, with increases projected for all climatic regions of Iran. Despite an overall projected mean precipitation increase of 36% for the year 2100, relative to that for 1961-1990, these are insufficient to compensate for temperature increases. Consequently, calculated water deficits during the growing season (autumn to spring) in Iran's wheat producing areas are expected to increase from 5.2% in 1980 to over 23% by 2050 and 38% by 2100.

Keywords: Simulation; GCM; Water requirement; Wheat; Autumn; Iran.

Introduction

It is now widely reported that increased atmospheric concentrations of trace gases such as CO_2, CH_4, N_2O, tropospheric O_3 and CFCs are enhancing the earth's natural greenhouse effect and accelerating global warming (Rosenberg et al., 2003; MacCracken, 2008; Allison et al., 2009). Over the past 25 years, mean global temperatures have risen by 0.19 °C per decade (Allison et al., 2009), whilst the projected global average surface temperature increase by the 2020s is expected to be ca. 1 °C, relative to the pre-industrial period (IPCC, 2007). The impacts of such global warming on climate variability, agriculture and water resources have become worldwide concerns (Gregory and Ingram, 2000; Sanchez, 2000; Fuhrer, 2003; Guo et al., 2009), and in Iran has included the study of such effects on the production of chickpea using the CYRUS model (Gholipoor, 2007). Under the combined impact of climate warming and increases in CO_2 concentration, crop production may be impacted through accelerated changes in soil (mainly changes in soil moisture) and air conditions; consequently affecting the physiological processes such as photosynthesis, respiration and partitioning of photosynthesis production (Chartzoulakis and Psarras, 2005; Yang and Zhang, 2006; Guo et al., 2009). Apart from mean global temperatures increasing, it is expected that a higher frequency of extreme temperature anomalies may have even more far reaching effects on crop activity (Körner et al., 2002; Wu et al., 2006). However, the IPCC (2007) report highlights that crop phenological responses differ regionally, with for example stem elongation for winter rye and the emergence of maize advancing by 10 and 12 days respectively in Germany, for the period 1961-2000. In contrast, rice yields have decreased in the Philippines between 1979 and 2003, owing to temperature increases of 0.35 °C (T_{max}) and 1.13 °C (T_{min}) (IPCC, 2007). Thus, in order to facilitate appropriate climate change projections and their likely impacts on specific crops, it is imperative that climate change trends and associated crop responses are determined at regional scales. Understanding the crop physiological changes in association with climate change is important in the context of planning and implementing other appropriate agricultural management practices, particularly through controlled water (irrigation, regulating surface flow) and agricultural (herbicides, insecticide, fertilizers) inputs. For instance, it is suggested that CO_2 fertilization may compensate the negative effects of temperature increases and reduced precipitation on crop yields (Brown et al., 2000; Ludwig and Asseng, 2006; Krishnan et al., 2007). Wheat crop accounts for 21% of global food production and 200 million hectares of farmland worldwide (Ortiz et al., 2008). To this end, considerable international work has examined the impact of climate change on wheat production and have modeled likely future impacts and yields for a variety of global regions, such as across Europe (e.g. Wolf and van Diepen, 1995; Iglesias et al., 2000; Olesen et al., 2000; Eitzinger et al., 2003), the USA (e.g. Tubiello et al., 2002), Australia (e.g. Reyenga et al., 2001; Luo et al., 2005) and China (e.g. Ge and Hua, 1994). Apart from isolated studies (e.g. Yano et al., 2007; Gholipoor, 2008; Haim et al., 2008), there is a dearth of published information concerning the impacts of climate change on wheat production in the Middle East. Iran is a major wheat producing nation, accounting for ca 2.5% of global production (14.5 million tons/a as 11th producer in the world) and 33.7% of Iranian food production, with an estimated 6.6 million hectares cultivated in a variety of regions including the arid (34%), semi arid (45.84%), Mediterranean/semi-humid (15.16%) and Hyper-humid (5%) regions (Iranian Ministry of Agriculture, 2010). Yet, little is known about recent climate change and projected future changes across Iran, and more pertinently, how climate change is likely to impact wheat production in future. The aims of this paper are firstly to demonstrate recent climate changes in major wheat producing regions of Iran, and secondly, to use the MAGICC (Model for Assessment of Greenhouse-gas Induced Climate Change) SCENGEN compound model to project future hydrological scenarios and requirements to sustain wheat production in this Middle Eastern region.

Material and Methods

Climate change trends

Climate data were obtained from the Iran Meteorological Organization (IRIMO) for 92 synoptic and climatological stations within Irans’ wheat producing regions. These regions are subdivided into arid (37 stations), semi-arid (26 stations), Mediterranean (19 stations) and hyper humid (10 stations) climate zones in Iran, as depicted in Figure 1. Normalized annual and seasonal maximum, minimum and mean temperatures were calculated for each climate zone, based on the collective data sets from all stations within the given climate zone. Mean annual and seasonal precipitation was similarly calculated for each of the climate zones. We present a 50-year (1960-2009) temperature and precipitation record for each of these climate zones and determine their overall trends. Unfortunately, instrumental climate records are largely absent for Iran pre 1960. The trend tests are classified into two parametric and nonparametric groups following the methods of Masoudian (2005), Roshan et al. (2011), Borna (2011) and Shakoor (2011).

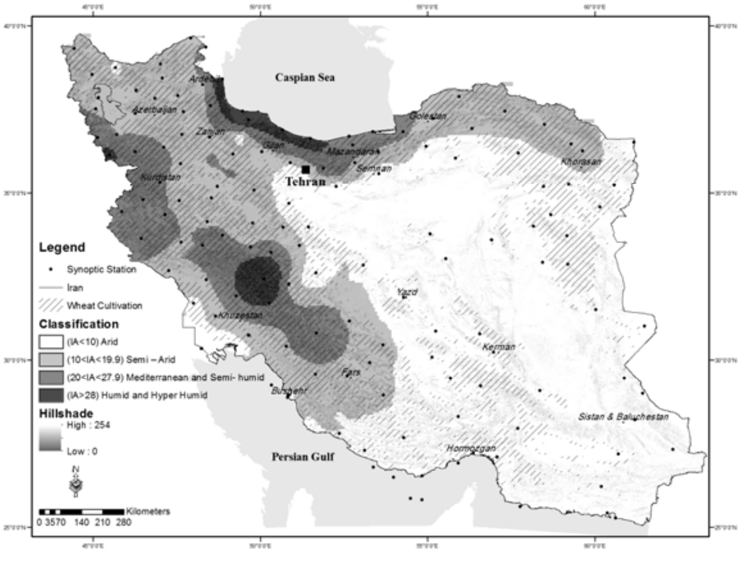

Figure 1. Various climatic regions of Iran based on De Marten’s modified system. The map also shows the synoptic and climatological stations from which data were obtained for this paper, as well as major wheat producing areas in the country. IA=Index of Demarten method.

Climate change models

We use the MAGICC/SCENGEN 5.3 compound model (Wigley, 1995) to project future warming in the various climate zones of Iran. In addition, 20 GCM models and a scenario referred to as ‘P50’, which is the average of SRES or emission scenarios, are used. MAGICC consists of a set of interrelated simple models which use parameters such as Carbon cycle, Nitrous oxide, Methane and aerosol forcing as inputs in the modeling process, the most important of which is climatic sensitivity. The MAGICC model is composed of a gas cycle, as well as snow melting models, which permit the user to determine the average global and regional temperature changes and the datum level changes according to greenhouse gas dispersion (Kont et al., 2003; Roshan et al., 2010a).

The regional and global SCENGEN model is not only a climate model, but it also includes results from 20 GCMs, as well as a set of global perceptual data and four sets of regional climate data (Kont et al., 2003). The SCENGEN software permits the user to make use of the results obtained from the MAGICC and general circulation models, and recognizes consequences when using different presuppositions with regards to climate system parameters.

Assessing the potential evapotranspiration and water requirements of wheat

The MAGICC SCENGEN model only simulates temperature, rainfall and pressure, and unlike models such as PENMAN and PENMAN MONITS, is unable to project future evapotranspiration. Given that these evapotranspiration models use very different climate parameters, the MAGICC SCENGEN model is unable to simulate these parameters. Thus, to simulate future evapotranspiration in Iran, the Blaney Cridle's method was used.

Upon simulation of evaporation and transpiration values, the water requirement (actual evaporation and transpiration) of wheat is calculated. In addition, to determine water balance, effective precipitation values (see Eq. 1) are calculated by using the Soil Conservation Service (SCS) method and deducted from actual evaporation and transpiration (water requirement) values.

$$P_e = F(1.253P^{0.824} - 2.935) \times 10^{0.001Et_p} \tag{1}$$

P_e=effective precipitation values; P=total precipitation for every month; ETP=total evapotranspiration for every month. Coefficient F is dependent on irrigation depth, which is taken as 0.75 mm in this project (Azizi, 2000).

Results

Temperature trends in Iran (1960-2009)

According to Masoudian (2005), mean minimum and maximum temperatures in Iran have respectively increased at a rate of 0.3 °C and 0.2 °C per decade over the past 50 years, with the most prominent increases in lowlands and arid regions. However, whilst temperature trends in the southern part of the Caspian Sea indicate a positive trend for daily minima (+0.45 °C/decade), those of daily maxima have a negative trend (-0.16 °C / decade) between 1950 and 2005, thus lowering the net temperature increases in this region (Aziz and Roshani, 2008). Recently, Roshan et al. (2010b) examined the impact of urban sprawl on the inter-decadal temperature trends for Tehran between 1952 and 2006, and record the most rapid increase (+0.90 °C/decade) during the last 10 years of this period.

Results from the current study indicate that 52% of Iranian stations used in this study show positive mean annual temperature trends, whilst 20% indicate a negative trend over the last 50 years (Figure 2). A higher percentage of stations record positive temperature trends during summer (52%) and spring (48%) than during autumn (44%) and winter (25%). Most notable is that whilst 64% of stations record positive mean annual T_{min} trends, only 33% record positive mean annual T_{max} trends. There is thus considerable variation in temperature trends between individual stations and across regions and seasons, with the greatest variation for stations located in semi-arid climatic regions of Iran (9% coefficient of variation) and the lowest variation for stations located in humid/hyper-humid climatic regions (5% coefficient of variation). The outcomes of the model projections in this paper thus have regional rather than site-specific value.

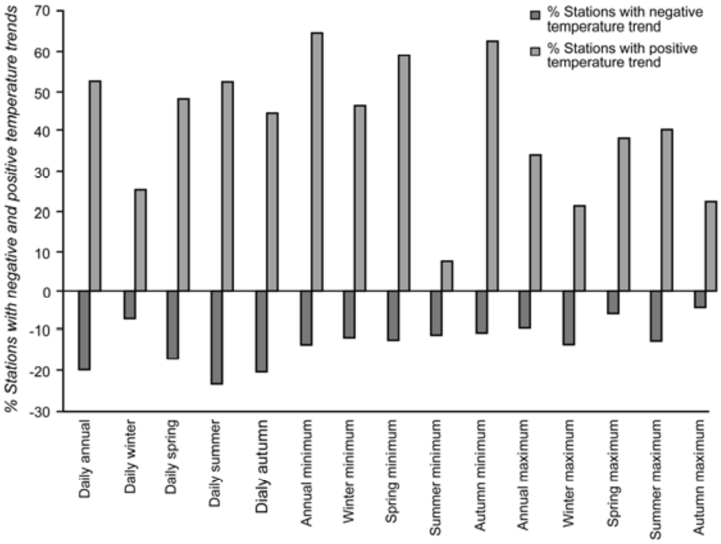

Figure 2. Percentage of stations across Iran displaying negative or positive temperature trends for the period 1960-2009.

Autumn is the most important season for wheat cultivation in Iran as this season is represented by relatively cool temperatures and the start of the wet season, and consequently best suited for cultivation. Precipitation usually begins in autumn, with two to three precipitation events totaling ca. 15-20 mm being required shortly after planting. We thus place emphasis on autumn climate trends (October to December). Results indicate positive T_{max} trends for arid (0.2 °C/decade; P=0.027; r=0.31) and semi-arid (0.09 °C /decade; P=0.472; r=0.10) regions of Iran, whilst those for Mediterranean and hyper-humid regions reflect slight negative trends of -0.07 °C/decade (P=0.548; r=0.08) and -0.03 °C/decade (P=0.675; r=0.05) respectively (Figure 3). However, T_{min} values indicate considerably stronger autumn warming trends, again exemplified for arid regions (0.65 °C/decade; P=0.000; r=0.76), and followed by humid/hyper-humid (0.4 °C/decade; P=0.000; r=0.57) and semi arid regions (0.16 °C/decade; P=0.068; r=0.26), whilst those for Mediterranean areas show little change (0.06 °C/decade; P=0.992; r=0.008)(Figure 4). Overall, mean autumn temperatures have increased in all climatic regions of Iran; these are most pronounced in arid regions (0.42 °C/decade; P=0.000; r=0.63), followed by humid/hyper-humid (0.21 °C/decade; P=0.017; r=0.33), semi-arid (0.09 °C/decade; P=0.334; r=0.13) and Mediterranean regions (0.05 °C/decade; P=0.548; r=0.09) (Figure 5).

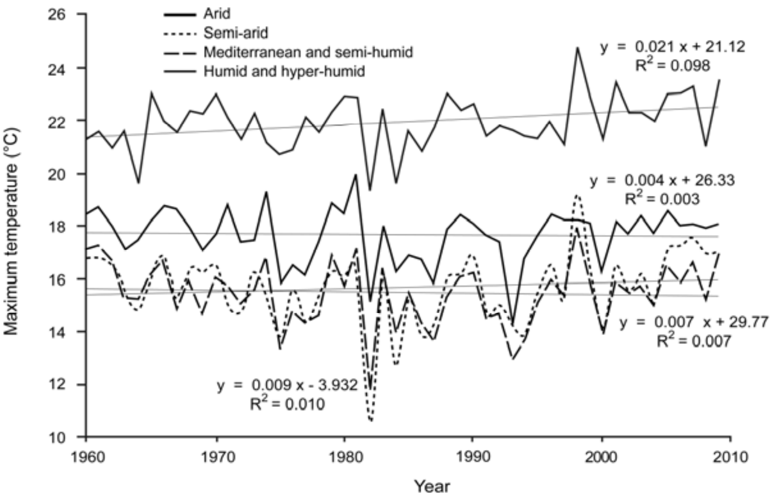

Figure 3. T_{max} trends during autumn for the four climatic zones of Iran, for the period 1960-2009.

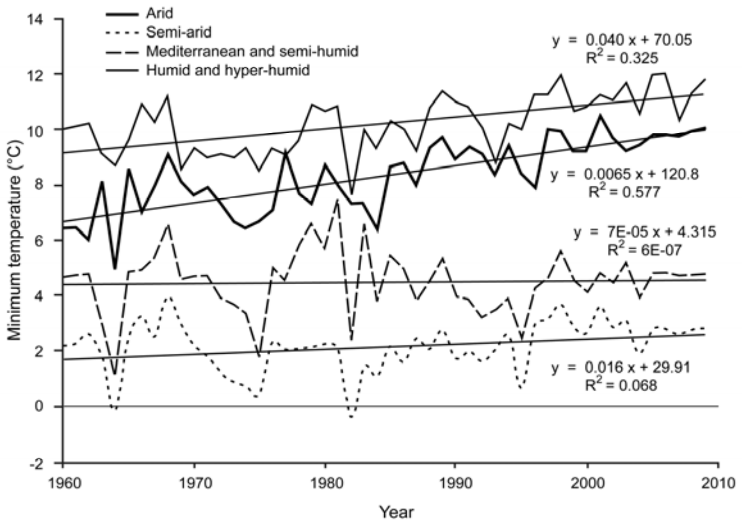

Figure 4. T_{min} trends during autumn for the four climatic zones of Iran, for the period 1960-2009.

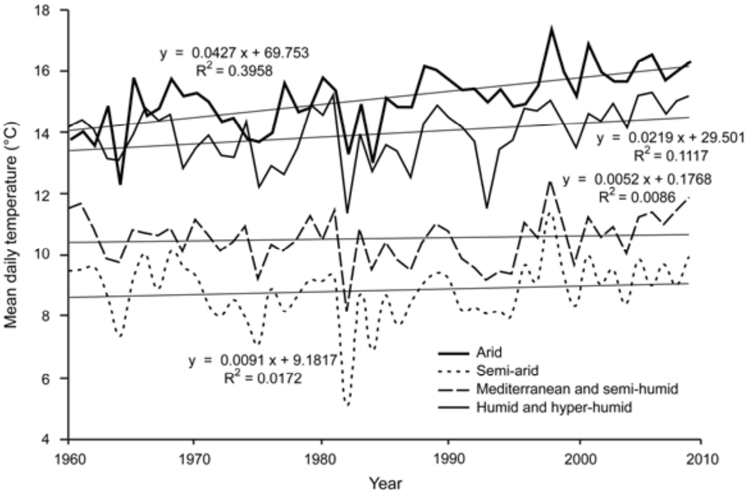

Figure 5. T_{mean} trends during autumn for the four climatic zones of Iran, for the period 1960-2009.

Statistically significant decreasing T_{mean} trends are recorded for winter months in arid (-0.39 ˚C/decade; P=0.016; r=-0.32) and semi-arid (-0.33 ˚C / decade; P=0.019; r=-0.32) climate zones. Other climate zones of Iran record no significant winter temperature trends between 1960 and 2009. During spring, significant T_{mean} (+0.27 °C/decade P=0.000; r=0.57), T_{max} (+0.39 °C / decade; P=0.004; r=0.38) and T_{min} (+0.13 °C/decade; P=0.007; r=0.36) increases are recorded in arid zones. Although Mediterranean climate zones also record mean increases in T_{max} (+0.59 °C/decade; P=0.000; r=0.63), those of T_{min} (-0.01 °C/decade; P=0.024; r=0.3) demonstrate a negligible trend. Humid/hyper-humid climate zones record significant decreases in T_{mean} (-0.3 °C/decade; P=0.007; r=0.37) during spring months. Arid and Mediterranean climate zones indicate significant positive mean summer temperature trends of +0.2 °C/decade (P=0.000; r=0.50) and +0.3 °C/decade (P=0.000; r=0.56) respectively, but those for semi-arid and humid/hyper-humid zones have decreased at a rate of -0.16 °C/decade (P=0.003; r=0.40) and -0.2 °C/decade (P=0.013; r=0.36) respectively.

Precipitation trends in Iran (1960-2009)

Given the importance of precipitation in wheat production, particularly in a region where rain fed water supply to crops is only marginally suitable for cultivation, it is appropriate to consider recent decadal changes in precipitation within the various wheat producing climatic regions of Iran. Given the importance of autumn and spring (April to June) for wheat growth in Iran, emphasis will be given to precipitation trends during these seasons.

According to Masoudian (2010), Iran's mean annual precipitation has increased at a rate of 5mm/decade over the past 50 years, and currently averages 250 mm/a. However, precipitation trends have been variable across the country, with summers generally becoming drier and winters wetter. Trends between individual stations are most varied in arid climatic regions of Iran (53% coefficient of variation) and lowest in humid/hyper-humid regions (30% coefficient of variation). To this end, whilst the precipitation trends outlined reflect mean sub-regional values, the high percentage of trend variability within particular regions needs to be acknowledged.

During autumn, a statistically significant positive rainfall trend is recorded for arid regions (+1.72 mm/decade; P=0.014; r=0.35), whilst those for semi-arid, Mediterranean and hyper-humid regions reflect insignificant trends (Figure 6a). Considering that wheat is planted during the autumn season, such precipitation trends in themselves are unlikely to have directly impacted wheat cultivation. Although not always significant, positive winter precipitation trends are recorded for Mediterranean (1.25 mm/decade;

P=0.029; r=0.30), humid/hyper-humid (0.65 mm/decade; P=0.601; r=0.07) and arid regions (0.73 mm/decade; P=0.106; r=0.22), whilst semi-arid regions record a statistically significant drop (-3.67 mm/decade; P=0.034; r=0.30) in winter precipitation (Figure 6b). Significant decreases in spring precipitation occur for arid (-0.72 mm/decade; P=0.098; r=-0.25), semi-arid (-3.2 mm; P=0.004; r=-0.42) and Mediterranean (-5.19 mm/decade; P=0.001; r=-0.45) regions, whilst humid/hyper-humid regions have experienced a non significant decrease in precipitation (-0.61 mm/decade; P=0.828; r=-0.03) (Figure 6c). This has important implications as wheat growth and maturity continues during spring. Thus, it seems that semi-arid and Mediterranean regions of Iran have been most impacted by precipitation decreases during the spring late growing season, with decreases of -16 mm (44.27%) and -25.95mm (45.13%) during the last five decades (1960-2009) respectively (Table 1).

Recent temperature and precipitation trends in Iran, relative to the 1961-1990 reference period

Temperatures are on average +0.52 °C higher during the period 2000-2009 than for the reference period 1961-1990, whilst precipitation values are on average 10% (-26 mm) lower during the latter period. However, whilst temperatures are consistently higher during the 2000-2009 period (1.65% coefficient of variation), precipitation values are highly variable (50% coefficient of variation) and annually range between +65% to -71.3% of the 1961-1990 mean. An inverse relationship (r=-0.56; P=0.097) between rainfall and temperature is recorded during the 2000-2009 period, which has important implications for water budgets.

Results indicate positive mean autumn-winter-spring (important wheat growing period) temperature trends for arid (+0.13 °C), semi-arid (+0.15 °C), Mediterranean (+0.48 °C) and hyper-humid (+0.55 °C) regions during the period 2000-2009, when compared with the reference period 1961-1990. Precipitation values are on average lower during the latter period for arid (-19.3%), semi-arid (-16.8%) and Mediterranean (-13%) regions, but higher for the hyper-humid (+5.5%) zone. However, whilst temperatures are consistently higher during the 2000-2009 period, with the greatest variation for stations located in semi-arid regions (4.5% coefficient of variation) and the lowest variation for stations located in humid/hyper-humid regions (0.41% coefficient of variation), precipitation values are highly variable with the coefficient of variation ranging between 52% (arid regions) and 35% (hyper-humid regions). Although there is a statistically significant inverse relationship between rainfall and temperature for Mediterranean (r=-0.62; P=0.056) and semi-arid (r=-0.57; P=0.080) regions during the 2000-2009 period, no statistically significant correlations are recorded for hyper-humid (r=-0.46; P=0.184) and arid zones (r=-0.06; P=0.869).

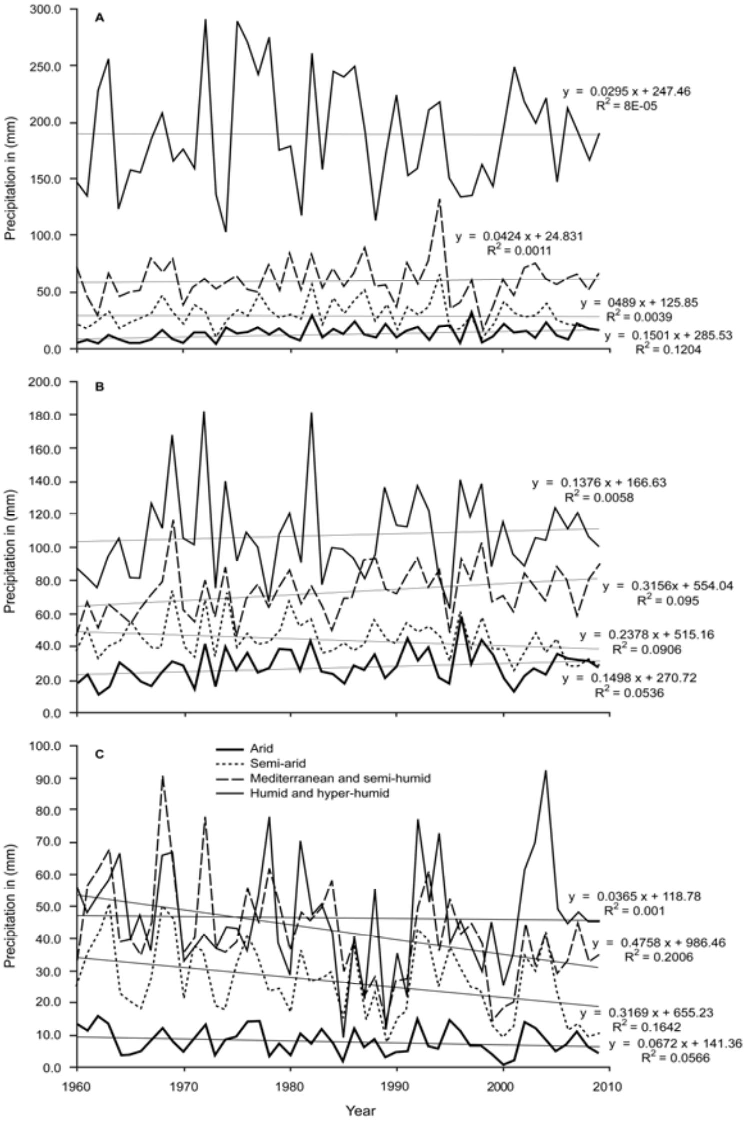

Figure 6. Precipitation trends during A) autumn, B) winter and C) spring for the various climatic zones of Iran, for the period 1960-2009.

Table 1. Seasonal temperature and rainfall changes for various climate regions of Iran: 1960-2009.

	Slope T (˚C/decade)	SE	R^2	P	Slope T (˚C/decade)	SE	R^2	P	Slope T (˚C/decade)	SE	R^2	P	Slope T (˚C/decade)	SE	R^2	P
	Arid				Semi-Arid				Mediterranean/ Semi-Humid				Humid/ Hyper Humid			
Autumn																
T_{Ave}	-0.08	0.78	0.04	0.263	-0.05	1.01	0.04	0.28	0	0.82	0.004	0.548	+0.05	0.902	0.004	0.611
T_{Max}	+0.09	0.97	0.02	0.336	-0.12	1.39	0.04	0.29	$+0.5^{***}$	1.22	0.25	0.000	+0.04	1.05	0.002	0.675
T_{Min}	$+0.17^{***}$	0.82	0.18	0.000	+0.02	0.88	0.01	0.41	0	1.19	0.02	0.499	+0.12	0.857	0.01	0.408
Winter																
T_{Ave}	-0.39^{***}	1.01	0.1	0.000	-0.33^{***}	2.01	0.1	0.02	-0.4	1.57	0.04	0.213	0	1.45	0.003	0.787
T_{Max}	+0.11	1.39	0.03	0.31	+0.04	2.07	0.03	0.32	0	1.89	0.03	0.199	-0.1^{***}	1.81	0.49	0.000
T_{Min}	-0.04	0.98	0.01	0.4	-0.15	2.02	0.03	0.31	-0.3	1.57	0.02	0.301	0	1.5	0	0.998
Spring																
T_{Ave}	$+0.39^{***}$	0.73	0.33	0.000	-0.02	0.87	0.02	0.39	-0.1	1.16	0.02	0.311	-0.3^{***}	0.91	0.14	0.007
T_{Max}	$+0.27^{***}$	0.87	0.15	0.000	-0.03	1.19	0.04	0.3	$+0.59^{***}$	1.47	0.4	0.000	-0.03	0.96	0.004	0.632
T_{Min}	$+0.13^{***}$	0.62	0.13	0.000	-0.06	0.8	0.01	0.41	-0.01^{**}	1.2	0.09	0.024	-0.06	0.81	0.001	0.794
Summer																
T_{Ave}	$+0.2^{***}$	0.48	0.25	0.000	-0.16^{***}	0.89	0.16	0.000	$+0.3^{***}$	1.04	0.32	0.000	-0.2^{**}	0.75	0.13	0.013
T_{Max}	$+0.13^{***}$	0.51	0.15	0.000	-0.17^{***}	0.74	0.15	0.000	$+0.64^{***}$	1.08	0.53	0.000	$+0.21^{*}$	0.91	0.06	0.065
T_{Min}	$+0.2^{***}$	0.66	0.26	0.000	+0.03	0.93	0	0.97	-0.2	1.49	0	0.953	$+0.16^{*}$	0.73	0.06	0.078
Rainfall	mm/decade															
Autumn	$+1.72^{***}$	5.98	0.12	0.000	-0.28	11.5	0	0.67	+0.51	18.7	0.001	0.817	+5.5	49.6	0	0.952
Winter	+0.73	9.27	0.05	0.10	-3.67^{**}	11.1	0.09	0.03	$+1.25^{**}$	14.3	0.09	0.029	+0.65	26.64	0.005	0.601
Spring	-0.74^{*}	4.04	0.05	0.10	-3.2^{***}	10.5	0.16	0.000	-5.19^{***}	14	0.2	0.001	-0.61	17.1	0.001	0.828
Summer	+0.02	0.51	0.01	0.5	+0.36	1.55	0.03	0.22	-1.9^{***}	6.49	0.18	0.002	-5.7	29.97	0.01	0.409

SE: standard error; R^2: linear regression; P: significance value.
Trends are significant with * $P<0.10$, ** $P<0.05$, *** $P<0.01$.

Correlation of real and simulated data

After simulation the increase of the autumn-winter-spring temperature by each model for the four climatic regions for the years 2000 to 2009, the total mean increase was calculated for the years 2000 to 2009. In order to identify the most suitable models, simple statistical calculations such as root mean square error (RMSE) to multivariable complicated calculations between models and observed variables were used and correlated. Correlation coefficients between the real and simulated temperature data are then used to identify the most suitable model for each climatic region (Figure 7a). It is evident from Figure 7a that the highest correlation coefficient between the temporal series of real and simulated data is for arid regions using the INMCM-30 model (r=0.86; P=0.001), whilst somewhat less strong correlations are found for semi-arid INMCM-30 model; r=0.79 (P=0.007), Mediterranean/semi-humid (UKHADCM3 model; r=0.66; P=0.039) and hyper-humid (GFDLCM20 model; r=0.70; P=0.024) zones.

The GISS-EH model outputs also present a strong correlation coefficient with real rainfall in semi-arid (r=0.88; P=0.001), hyper-humid (r=0.78; P=0.008), Mediterranean/semi-humid (r=0.68; P=0.028) and arid (r=0.74; P=0.014) regions (Figure 7b). Although the CNRM-CM3 model simulates the data *process* better than the GISS-EH model, it does not simulate the *values* as well as the GISS-EH (r=0.55; P=0.099) model (Figure 8); we thus use the combined results of the two models to simulate rainfall in arid regions of Iran, whilst for other climatic zones we only use the GISS-EH model. Some of the r values for real and simulated data indicate very strong negative correlations, such as for temperature in semi-arid regions (r=-0.91 in CSIRO-30). However, in such cases the models simulate conditions of real and simulated data inversely, thus making it necessary to select models that can simulate r as a positive value, even though their values may be lower than those depicting a negative r value.

Simulating future temperature and rainfall

The simulation (projection) results of temperature values using the proposed INMCM-30 (for arid and semi-arid regions), UKHADCM3 (for Mediterranean regions) and GFDLCM20 (for hyper-humid regions) models for the years 2025, 2050, 2075 and 2100 are provided in Table 2. Mean temperature increases during all months but increase most during August (by 5.78 °C; 0.48 °C/decade) and least during February (by 3.65 °C; 0.30 °C/ decade) for the period 1980 to 2100. The overall projected annual temperature increase for Iran for the period 1980-2100 is 4.61 °C (0.38 °C / decade), with the warmest (July) and coolest (January) months having projected mean monthly temperatures of 35.05 ˚C and 9.15 ˚C respectively by 2100. Projected seasonal temperature increases are most rapid in summer (by 5.3 ˚C; 0.41 ˚C/decade), followed by autumn (by 4.7 ˚C; 0.36 ˚C/ decade), spring (by 4.3 ˚C; 0.33 ˚C/decade) and winter (by 4.2 ˚C; 0.32 ˚C/ decade) for the period 1980-2100. Such projections may be compared to changes observed for the period 1960-2009, during which time the overall trends in Iran were highest for summer (+0.06 ˚C/decade), followed by spring (+0.01 ˚C/decade) autumn (-0.02 ˚C/decade) and winter (-0.28 ˚C/ decade). Hence, whilst spring temperatures have increased more rapidly than autumn temperatures during the last 50 years, it is projected that the future trend will be reversed (Tables 2 and 3).

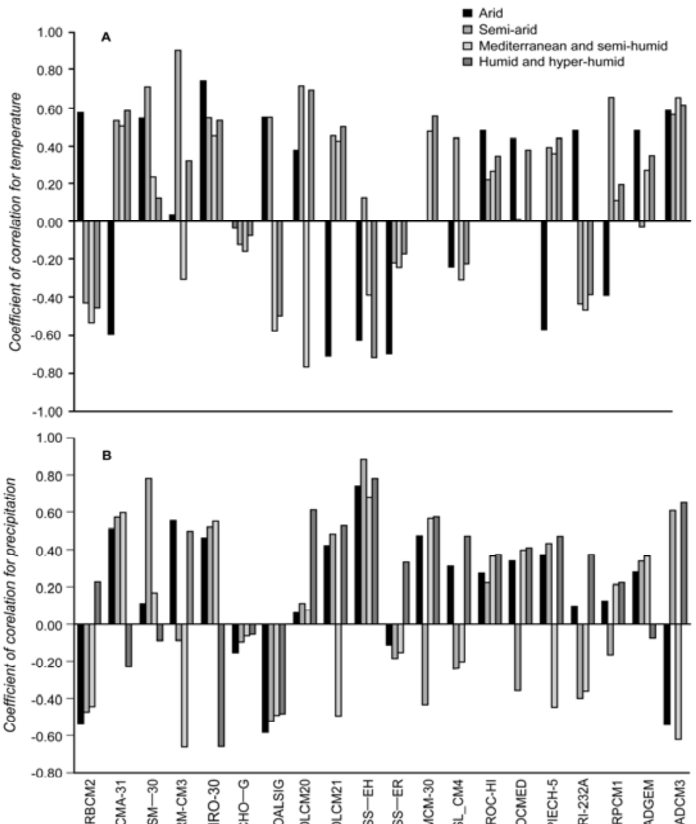

Figure 7. Correlation coefficients between the real and simulated data series for A) temperature and B) precipitation using various GCMs.

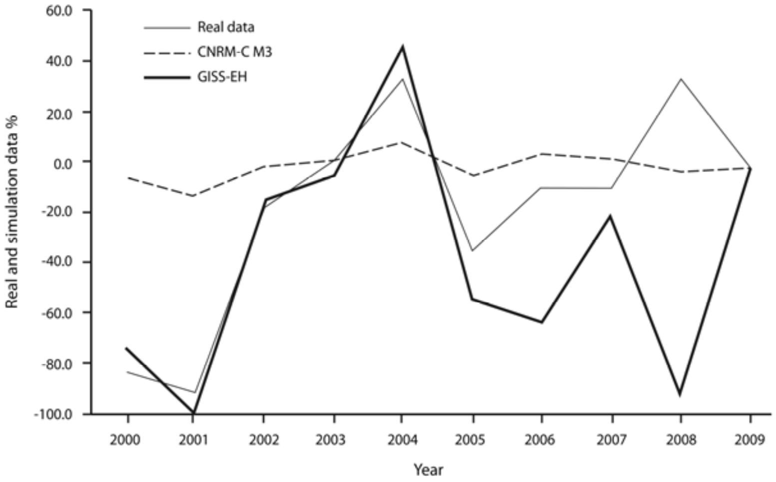

Figure 8. Comparison of simulated and real data series of rainfall using the GISS-EH and CNRM-CM3 models, for the period 2000-2009.

Table 2. Simulated (projected) mean seasonal temperature values for different climate regions of Iran (˚C).

Years	Climatic region	Winter	Spring	Summer	Autumn
2025	Arid	12.48	26.52	30.94	17.32
	Semi-Arid	3.62	17.89	24.98	9.28
	Mediterranean and Semi- humid	9.2	22.2	29.19	14.93
	Humid and Hyper Humid	7.36	18.47	25.34	12.76
2050	Arid	13.49	27.66	32.26	18.41
	Semi-Arid	4.59	18.9	26.19	9.96
	Mediterranean and Semi- humid	10.07	23.19	30.59	15.66
	Humid and Hyper Humid	7.94	19.35	26.82	13.41
2075	Arid	14.3	28.74	32.91	19.25
	Semi-Arid	5.39	19.88	27.87	10.57
	Mediterranean and Semi- humid	10.97	24.34	31.69	16.26
	Humid and Hyper Humid	8.48	20.01	27.5	14.07
2100	Arid	15.25	30.06	34.6	20.1
	Semi-Arid	6.28	20.87	28.81	11.13
	Mediterranean and Semi- humid	11.89	25.14	32.86	16.89
	Humid and Hyper Humid	9.58	20.79	28.6	14.27

Table 3. Mean past temperatures and future projected temperature changes for Iran.

Months	Mean (˚C)	T (˚C) increase or decrease relative to the 1960-1990 references period						T (˚C) increase between
	1960-1990	1980	2005	2025	2050	2075	2100	1980 and 2100
Jan	5.81	-0.78	0.79	1.03	1.93	2.6	3.34	4.12
Feb	7.51	-0.44	-0.02	0.96	1.8	2.44	3.22	3.65
Mar	11.66	-0.29	-0.13	1.17	2.35	3.47	4.76	5.05
Apr	17.56	0.06	2.97	0.61	1.69	2.8	4.1	4.04
May	22.5	0	2.05	1.23	2.31	3.37	4.46	4.45
Jun	26.93	0.2	0.01	1.14	2.21	3.17	4.29	4.09
Jul	29.13	0.07	0.39	1.3	2.6	3.79	4.92	4.85
Aug	28.25	-0.25	0.66	1.49	2.99	4.14	5.52	5.78
Sep	24.54	0.03	0.88	1.81	2.92	3.96	5.28	5.25
Oct	19.13	-1.3	-0.37	1.2	2.27	3.16	3.82	5.12
Nov	12.93	-0.68	-1.13	1.37	2.25	2.95	3.9	4.58
Dec	8.04	-1.26	0.61	1.01	1.81	2.45	3.05	4.31
Mean	17.83	-0.39	0.56	1.19	2.26	3.19	4.22	4.61

More importantly, the simulated temperature increases for the various wheat producing climate zones of Iran need to be considered. All climate zones indicate mean projected temperature increases for the period 1980-2100. Arid zones indicate the greatest temperature increases for autumn (by 2.97 °C; 0.27 °C/decade), winter (by 2.48 °C; 0.23 °C/decade), and spring (by 2.81 °C; 0.26 °C/decade), whilst semi-arid regions are projected to experience greatest summer warming (by 3.57 °C; 0.32 °C/decade) by 2100. Mean winter temperatures are projected to increase by between 2.57 °C (0.20 °C/decade) in arid zones and 2.13 °C (0.16 °C/decade) in humid/hyper humid zones for the period 2025-2100, whilst those for summer are projected to increase by between 3.70 °C (0.28 °C/decade) in semi-arid zones to 3.14 °C (0.24 °C/decade) in humid/hyper-humid zones. Mean spring temperatures are projected to increase by between 3.42 °C (0.26 °C/decade) in arid zones and 2.22 °C (0.17 °C/decade) in humid/hyper-humid zones, whilst those in autumn between 2.63 °C (0.20 °C/decade) in arid zones and 1.37 °C (0.11 °C/decade) in humid/hyper-humid zones. Hence, greatest temperature increases are expected in arid zones of Iran and lowest increases in humid/hyper-humid zones. The findings have important implications for wheat cultivation in Iran, which is currently based on dry farming, with limited irrigation input. Firstly, the projected temperature increases during autumn and winter impacts the thermal thresholds for growth and maturity of wheat and is likely to considerably prolong the growing season by the year 2100. Secondly, increasing temperatures will accelerate evapotranspiration rates and increase the water requirements of wheat in autumn and more particularly during spring.

The simulated rainfall results using the CISS-EH and CNRM-CM3 models in arid regions and the CISS-EH model in other regions do not indicate substantial future changes, although considerable oscillations are projected until 2100 (Table 4). Model results indicate that mean annual rainfall amounts for Iran vary from a minimum of 191 mm in 2001 to 339 mm in 2100. All future periods indicate simulated increases in precipitation, compared with the 1961-1990 average of 283 mm. More important to consider are the simulated (projected) precipitation changes during the critical wheat growing seasons in Iran, namely autumn to spring. Simulation results indicate increases in precipitation during most autumn and winter months, with the exception of January (Figure 9). However, the considerable projected precipitation increases (over 20%) in February compensate for the below 20% decreases in January. Results indicate a reduction in projected precipitation for the spring months of April/May when crops are maturing, just before wheat harvesting. Whilst precipitation currently peaks during the month of March, and is expected to continue peaking during this month until the simulated year of 2050, the models indicate that peak precipitation should shift to February by 2075 and continue this trend until at least 2100.

Table 4. Simulated (projected) precipitation values for different seasons and climate regions of Iran.

Years	Climatic region	Winter	Spring	Summer	Autumn
2025	Arid	45	-14	110	97
	Semi-Arid	11	-42	71	44
	Mediterranean and Semi-humid	26	-4	53	54
	Humid and Hyper Humid	-9	-23	29	24
2050	Arid	87	-9	173	162
	Semi-Arid	10	-42	126	32
	Mediterranean and Semi-humid	48	-59	54	43
	Humid and Hyper Humid	10	-33	45	20
2075	Arid	92	25	184	115
	Semi-Arid	-22	-24	122	53
	Mediterranean and Semi-humid	55	-136	90	50
	Humid and Hyper Humid	0	77	27	24
2100	Arid	138	-22	236	140
	Semi-Arid	-4	-155	190	34
	Mediterranean and Semi-humid	71	-128	99	47
	Humid and Hyper Humid	36	35	76	-14

Values are a % relative to the 1961-1990 reference period.

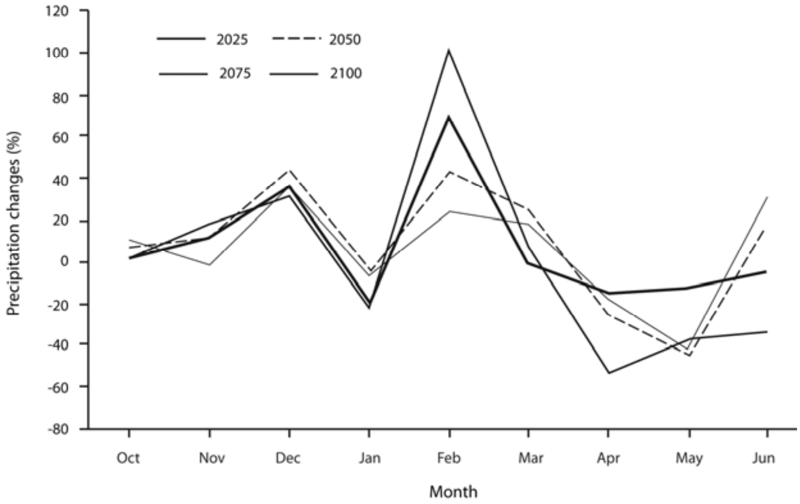

Figure 9. Ratio of Iran's projected future precipitation changes during autumn, winter and spring, relative to the 1961-1990 reference period.

More importantly, the simulated rainfall changes for the various wheat producing climate zones of Iran need to be considered. Autumn is the most important season for wheat crops in Iran as this is the planting season, and in almost all simulated years and climate regions there are projected increases in rainfall during this season, relative to the 1961-1990 reference period (Tables 4 and 5). Notably, arid regions are expected to encounter maximum precipitation increases during autumn (by between 74 mm [140% increase] in 2100 and 90.72mm [162% increase] in 2050). Projected precipitation increases are expected for most years and climatic regions during winter when the wheat crop is relatively dormant, and particularly so for arid areas in Iran. However, winter precipitation is projected to begin declining in semi-arid regions by at least 2075. The second most important season for wheat production is spring, when crop growth is revived after winter dormancy. Notably, the model projections indicate significant (r=-0.74; P=0.009) precipitation decreases during spring for all climate zones during the next few decades, with the most substantial decreases simulated for semi-arid (up to -155% decline by 2100) and Mediterranean/semi-humid regions (up to -136% decline by 2075) (Tables 4 and 5).

Table 5. Mean past and projected future monthly rainfall (mm) for Iran. R values indicate trends for various months and seasons from 2025 to 2100.

Month	1980	2005	2025	2050	2075	2100	R (2025-2100) Monthly	R (2025-2100) Seasonally
Jan	40.07	50.25	36.85	35.2	30.99	28.01	-0.99	
Feb	31.51	20.88	43.81	51.6	60.06	72.44	0.99	0.82
Mar	39.11	27.13	55.26	59.1	49.7	52.77	-0.55	
Apr	36.12	7.51	25.66	24.06	22.72	20.53	-0.99	
May	25.57	6.14	12.18	11.1	14.51	13.11	0.55	-0.74
Jun	4.27	7.91	8.78	9.34	9.13	7.85	-0.59	
Jul	5.31	1.09	5.48	5.94	5.42	6.61	0.67	
Aug	2.63	9	7.6	8.97	9.65	10.77	0.99	0.97
Sep	10.3	23.77	11.8	13.42	13.95	14.57	0.96	
Oct	18.28	22.54	23.83	23.96	22.59	23.14	-0.7	
Nov	29.08	30.99	26.99	30.38	30.93	32.1	0.93	0.39
Dec	46.8	48.47	54.52	62.4	56.78	57.01	0.07	
Mean	289.05	255.68	312.75	335.5	326.41	338.91	-	-

R: linear regression (Correlation coefficients).

Future water requirements for wheat production in Iran based on observational and simulated data

The future water requirements of wheat in Iran are simulated (projected) and compared with the observational data for the years 1980 and 2005. Figure 10 indicates past, recent and future projections of both the actual water required (precipitation in mm) for wheat production and the water deficit (mm) for such production in Iran. Values of water deficit or surplus are determined by deducting evapotranspiration values from Effective Precipitation values (EP). Given that much of Iran is arid to semi-arid, the country as a whole encounters considerable water deficit during the growth period of wheat, and this deficit is set to become exacerbated at least until 2100. There is both an increasing annual trend of water deficit (R=0.95) and water requirement (R=0.98) over the period 1980-2100. However, autumn (R=0.93) and winter (R=0.90) water deficits are lower than those in spring (R=0.98) and summer (R=0.97).

Sub-regional water deficits/surplus for autumn, winter and spring seasons, for the various climate zones of Iran, are modeled (projected) and mapped for future decades using the MAGICC SCENGEN software (Figure 11). Observational and simulated data indicate maximum water surplus in humid/hyper-humid regions of Iran, which include the region west of Gilan and the Caspian Sea. According to model outputs, these regions should maintain positive water balances at least until 2100, whilst all other regions of Iran are expected to encounter water deficits during forthcoming decades.

The zones of western Semnan, northwestern Golestan and Mazandaran are located in the Mediterranean semi-humid region; these have the lowest water deficits in the observational periods (1980 and 2005). However, minor water budget changes occur in the simulated periods (2025 to 2100) for southern Azerbaijan, western Zanjan, northern Kurdistan, Ardebil and western Gilan; these project improved water budgets, even over those of western Semnan, northwestern Golestan and Mazandaran for the years 2050 and 2075. Although the zones Kurdistan, Ardebil and western Gilan are located in the semi-arid region, these have lower projected evapotranspiration values and water deficits for the years 2050 and 2075, in comparison with other semi-arid regions of Iran due to their high altitude (i.e. cooler conditions) accompanied with lower projected temperature increases (2 ˚C as opposed to 2.47 ˚C for all semi-arid regions by 2100).

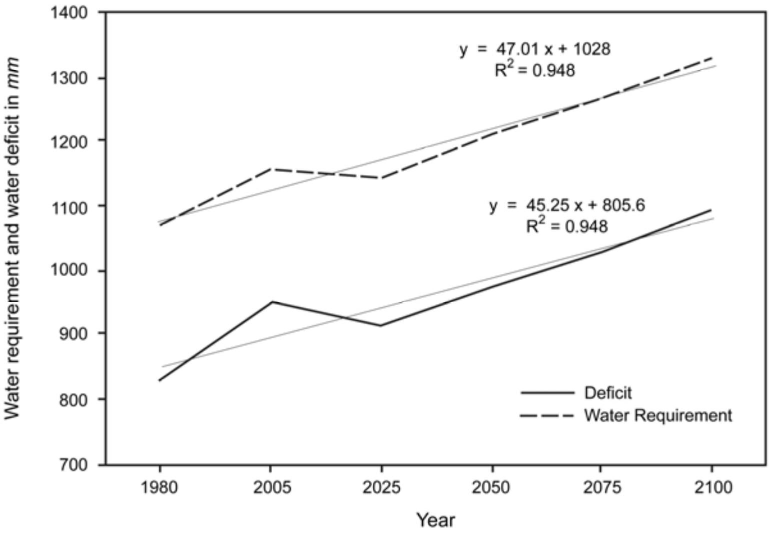

Figure 10. Past, present and projected future water requirements and deficits for autumn-winter-spring wheat production in Iran.

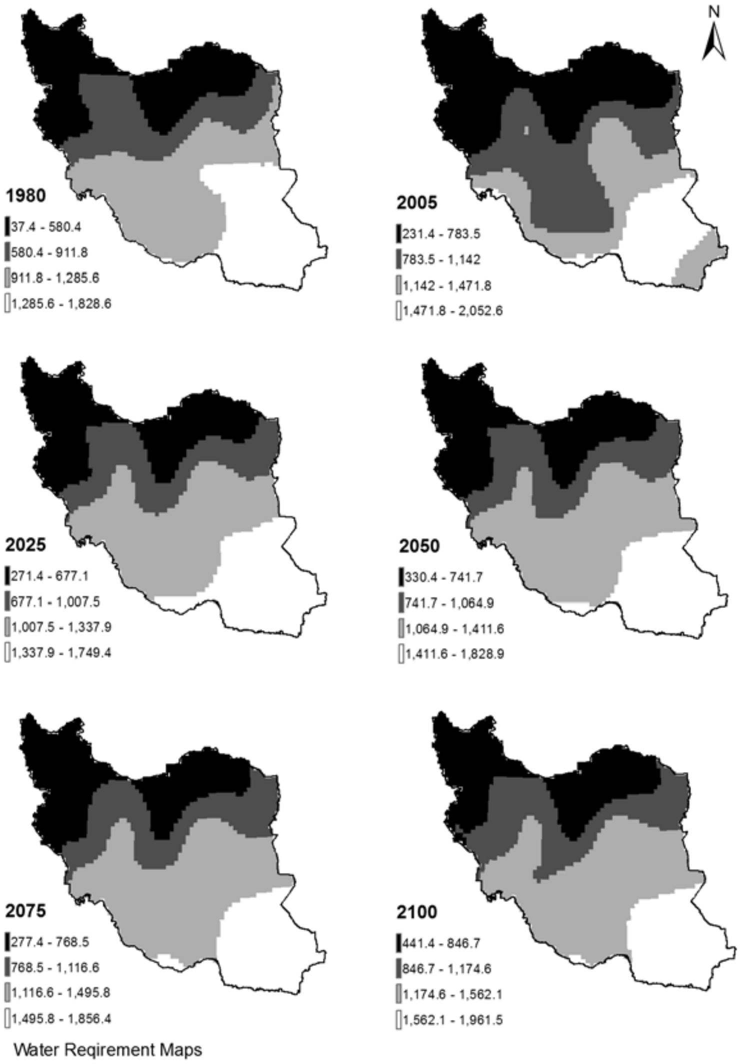

Figure 11. Total autumn-winter-spring water deficit/surplus in various wheat producing regions of Iran for the years: 1980, 2005, 2025, 2050, 2075 and 2100.

Calculations indicate that annual water deficits, and particularly those during the growth period of wheat, are highest in the southeastern and southern regions of Iran where projected deficits increase from 1857 mm in 1980 to 2008 mm by 2100. The areas include southern and western Sistan, southern and western Kerman, eastern Hormozgan, eastern and western

Sistan, Baluchestan, eastern Bushehr, eastern Persian Gulf, and southern Fars. Notably, these zones are located in the arid climatic zone of Iran, and given their low rainfall and high temperatures (and associated evapotranspiration rates), encounter water stress for dryland farming.

Although strong correlations (significant at P<0.0001) are observed between precipitation and water deficits for the years 1980 (r=-0.66), 2005 (r=-0.53), 2025 (r=-0.67), 2050 (r=-0.63), 2075 (r=-0.66) and 2100 (r=-0.57), temperature has a stronger role in influencing water deficits for the years 1980 (r=0.67), 2005 (r=0.76), 2025 (r=0.77), 2050 (r=0.78), 2075 (r=0.72) and 2100 (r=0.71). Despite projected precipitation increases in arid regions of Iran, and a correlation of precipitation and water deficits of r=-0.53 by 2100, these regions are expected to experience higher warming trends than other regions, such that rising temperatures are the dominant factor controlling future water deficits in arid regions, where r=0.81 by 2100. Water deficits in semi-arid and Mediterranean/semi-humid regions of Iran will similarly owe their future water deficits to the stronger role of rising temperatures where r=0.74 and 0.72 respectively, rather than changes in rainfall where r=-0.59 and -0.62 respectively. However, in humid/hyper-humid regions of Iran, water deficits by 2100 correlate more strongly with projected precipitation (r=-0.78) than temperature (r=0.69).

Discussion

Results indicate a relatively high percentage (52%) of stations recording positive temperature trends during summer in arid, Mediterranean/semi-humid and humid/hyper-humid regions of Iran. Although only 25% of Iranian stations record temperature increases during winter, some temperature attributes have significantly increased in arid and Mediterranean/semi-humid regions during spring and in Mediterranean/semi-humid regions during autumn. Overall, these temperature trends agree with trends measured across other Middle Eastern regions, which demonstrate highest increases during spring and/or summer and virtually no warming or even slight cooling, during winter (Nasrallah and Balling, 1993; Ben-Gai et al., 1999; Türkes and Sümer, 2004).

Despite the significant decline in mean spring precipitation between 1960 and 2009 in Iran, also important for wheat cultivation is that autumn precipitation has not significantly declined, whilst winter precipitation has marginally increased during this period. However, winter precipitation in semi-arid regions has recorded statistically significant declines. Again, it needs to be recognized that these are normalized results for the various climatic regions of Iran and that considerable variability in trends exist between stations and regions. Such lack of spatial coherence in long-term precipitation trends have previously been confirmed for arid and semi-arid regions of Iran (Modarres and de Paulo Rodrigues da Silva, 2007), as well as in other parts of the Middle East (Zhang et al., 2005). Notwithstanding this, it is worth summarizing the rates of mean annual temperature/rainfall changes in the various climate zones of Iran for the period 1960-2009: arid =(+0.1 °C/decade; +0.43 mm/decade), semi-arid=(-0.1 °C/decade; -1.7 mm/decade), Mediterranean/semi-humid=(+0.1 °C/decade; -1.33 mm/ decade), humid/hyper-humid = (-0.01 °C/decade; -0.04 mm/decade).

Twenty GCM models have been tested to best simulate Iranian temperature and precipitation for observational data from 2000 to 2009, with the best outcomes for temperature being the INMCM-30 model in arid and semi-arid regions, the UKHADCM3 model in Mediterranean/semi-humid regions and the GFDLCM20 model in hyper-humid regions. For precipitation, best outcomes are using the combined CNRM-CM3 and GISS-EH models for arid regions and the GISS-EH model for semi-arid, Mediterranean/semi-humid and humid/hyper-humid climate zones. Temperature simulations (projections) to 2100 indicate an overall temperature increase of ca. 4.25 °C relative to that for 1961-1990. Model outputs indicate that temperatures will continue to increase in all climatic regions of Iran. For the important wheat cultivation seasons of autumn, winter and spring, temperatures are projected to rise most substantially in arid regions (1.19 °C by 2025; 4.32 °C by 2100) and least in humid/hyper-humid regions (0.82 °C by 2025; 3.69 °C by 2100). Rainfall simulations (projections) indicate an overall mean annual increase of ca 88.9 mm (36%) for the country by 2100, relative to that for 1961-1990. For the important wheat production months, precipitation on average is projected to increase during autumn and winter by 69.5 mm (35.4%) by 2100, whilst that for spring is projected to decrease by 41.5 mm (-32.8%).

Projected water requirements for wheat cultivation during the growing seasons are expected to increase significantly ($P<0.001$) due to accelerated warming. The mean annual projected water deficit for Iran is 2007.9 mm for 2100, which is up from 1856 mm in 1980. However, the average projected water requirements for wheat cultivation during the growing seasons (autumn to spring) in Iran will increase from 831 mm in 1980 to 1090 mm in 2100. Despite the projected precipitation increases during autumn and winter, these are insufficient to account for decreasing precipitation during spring and greater evaporation rates due to warming. Consequently, water deficits during the growing seasons (autumn to spring) in Iran's wheat producing areas are expected to increase from 5.2% in 1980 to over 23% by 2050 and 38% by 2100. Despite such future water deficits, the humid/hyper-humid regions of Gilan, western Mazandaran, Rasht, Astara and eastern Ardebil are projected to continue experiencing water surplus until 2100. In addition, semi-arid regions of northern Kurdistan, western Zanjan, Azerbaijan, Ardebil, western Gilan, northwestern Golestan, Mazandaran, Semnan and northern Yazd may expect improved water budgets over the next 80 years. However, the dryland wheat producing areas of eastern Hormozgan, southern and western Kerman, southwestern Sistan, western and eastern Sistan, Baluchestan, eastern Bushehr and southern Fars are likely to be most negatively impacted by water deficits during forthcoming decades.

Conclusion

Iranian farmers cultivate on average 6.6 million hectares of wheat per annum, of which only 2.6 million hectares (39%) is irrigated (Iranian Ministry of Agriculture, 2010). The remaining 4 million hectares (61%) of wheat is entirely reliant on rainfall during its growth cycle. Based on our climate projections, it is estimated that 55% of current wheat producing areas in Iran will require irrigation by 2050 and 77% by 2100. However, the scarcity of surface water supply through rivers, lakes and ground water in most wheat producing regions of Iran is likely to spatially limit the potential for irrigation, which has critical implications for future wheat production in a nation which is so reliant on this staple crop.

References

Allison, I., Bindoff, N.L., Bindschadler, R.A., Cox, P.M., De Noblet, N., England, M.H., Francis, J.E., Gruber, N., Haywood, A.M., Karoly, D.J., Kaser, G., Le Quéré, C., Lenton, T.M., Mann, M.E., McNeil, B.I., Pitman, A.J., Rahmstorf, S., Rignot, E., Schellnhuber, H.J., Schneider, S.H., Sherwood, S.C., Somerville, R.C.J., Steffen, K., Steig, E.J., Visbeck, M., Weaver, A.J., 2009. The Copenhagen Diagnosis: Updating the World on the Latest Climate Science. The University of New South Wales, Climate Change Research Centre (CCRC), Sydney, Australia, 60p.

Azizi, G.H., Roshani, M., 2008. Studying the climate changes in the southern coasts of the Caspian Sea based on Man-Condal Method. Geogr. Stud. 64, 13-28. (In Persian)

Azizi, G.H., 2000. Evolution of effective precipitation values in relationship with cultivation of dry wheat, Case study: Khoram Abad plain. Geogr. Stud. 39, 115-123. (In Persian)

Ben-Gai, T., Bitan, A., Manes, A., Alpert, P., Rubin, S., 1999. Temporal and spatial trends of temperature patterns in Israel. Theor. Applied. Clim. 64, 163-177.

Borna, R., 2011. Elevation of Spatio-Temporal Variation of Recent & Future Evapotranspiration Trends In Arid Areas of Iran (Case Study: Yazd). Inter. J. Physical. Sci. 16, 3971-3978.

Brown, R.A., Rosenberg, N.J., Hays, C.J., Easterling, W.E., Mearns, L.O., 2000. Potential production and environment effects of switchgrass and traditional crops under current and greenhouse-altered climate in the central United States: a simulation study. Agric. Ecosys. Environ. 78, 31-47.

Chartzoulakis, K., Psarras, G., 2005. Global change effects on crop photosynthesis and production in Mediterranean: the case of Crete, Greece. Agric Ecosys Environ. 106, 147-157.

Eitzinger, J., Štatná, M., Žalud, Z., Dubrovský, M., 2003. A simulation study of the effect of soil water balance and water stress on winter wheat production under different climate change scenarios. Agric. Water. Manag. 61, 195-217.

Fuhrer, J., 2003. Agroecosystem responses to combinations of elevated CO2, ozone, and global climate change. Agric. Ecosys. Environ. 97, 1-20.

Ge, J.Z.F.J., Hua, D.X.C., 1994. Prospects to the impacts of Climate Change on winter wheat production in China. Acta. Agron. Sinica. 2, 8.

Guo, R., Lin, Z., Mo, X., Yang, C., 2009. Responses of crop yield and water use efficiency to climate change in the North China Plain. Agric. Water. Manag. 97, 1185-1194.

Gholipoor, M., 2007. Potential effects of individual versus simultaneous climate change factors on growth and water use in chickpea. International J. Plant Prod. 2, 189-204.

Gholipoor, M., 2008. Qualifying the threshold frost hardiness over-wintering survival of wheat in Iran, using simulation. International J. Plant Prod. 3, 125-136.

Gregory, P.J., Ingram, J.S.I., 2000. Global change and food and forest production: future scientific challenges. Agric. Ecosys. Environ. 82, 3-14.

Haim, D., Shechter, M., Berliner, P., 2008. Assessing the impact of climate change on representative field crops in Israeli agriculture: a case study of wheat and cotton. Clim. Change. 86, 425-440.

Iglesias, A., Rosenzweig, C., Pereira, D., 2000. Agricultural impacts of climate change in Spain: developing tools for a spatial analysis. Global. Environ. Chang. 10, 69-80.

IPCC, 2007. Climate change 2007. The physical science basis. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Iran Meteorological Organization (IRIMO): http://www.irimet.net.

Iranian Ministry of Agriculture, 2010. Annual report in the management of crops, part II, wheat. Iranian Ministry of Agricultural, Tehran, Iran. (In Persian)

Kont, A., Jaagus, J., Aunap, R., 2003. Climate Change scenarios and the effect of sea-level rise for Estonia. Glob. Planet. Chang. 36, 1-15.

Körner, O., Challa, H., Van Ooteghem, R.J.C., 2002. Modeling temperature effects on crop photosynthesis at high radiation in a solar greenhouse. Acta. Horticult. 593, 137-144.

Krishnan, P., Swain, D.K., Bhaskar, B.C., Nayak, S.K., Dash, R.N., 2007. Impact of elevated CO_2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agric. Ecosys. Environ. 122, 233-242.

Ludwig, F., Asseng, S., 2006. Climate change impacts on wheat production in a Mediterranean environment in Western Australia. Agric. Syst. 90, 159-179.

Luo, Q., Bellotti, W., Williams, M., Bryan, B., 2005. Potential impact of climate change on wheat yield in South Australia. Agric. Forest. Met. 132, 273-285.

MacCracken, M.C., 2008. Prospects for future climate change and the reasons for early action. Air. Waste. Manag. Assoc. 58, 735-786.

Masoudian, A., 2005. Study of Iranian temperatures in the recent half-century. Geogr. Stud. 54, 29-45. (In Persian)

Masoudian, A., 2010. Climatology of Iran. University of Esfahan Press, Esfahan, Iran, 191p. (In Persian)

Modarres, R., De Paulo Rodrigues da Silva, V., 2007. Rainfall trends in arid and semi-arid regions of Iran. J. Arid. Environ. 70, 344-355.

Nasrallah, H.A., Balling, R.C., 1993. Spatial and temporal analysis of Middle Eastern temperature changes. Clim. Chang. 25, 153-161.

Olesen, J.E., Jensen, T., Peterson, J., 2000. Sensitivity of field-scale winter wheat production in Denmark to climate variability and climate change. Clim. Res. 15, 221-238.

Ortiz, R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, D., Dixon, J.M., Ortiz-Monasterio, J.I., Reynolds, M., 2008. Climate Change: can wheat beat the heat? Agric. Ecosys. Environ. 126, 46-58.

Reyenga, P.J., Howden, S.M., Heinke, H., Hall, W.B., 2001. Global change impacts on wheat production along an environmental gradient in South Australia. Enviro. Int. 27, 195-200.

Rosenberg, N.J., Brown, R.A., Cesar Izaurralde, R., Thomson, A.M., 2003. Integrated assessment of Hadley Centre ($HadCM_2$) climate change projections on agricultural productivity and irrigation water supply in the conterminous United States: I. Climate change scenarios and impacts on irrigation water supply simulated with the HUMUS model, Agric. Forest. Met. 117, 73-96.

Roshan, G.h.R., Ranjbar, F., Orosa, J.A., 2010a. Simulation of global warming effect on outdoor thermal comfort conditions. Int. J. Enviro. Sci. Tech. 7, 571-580.

Roshan, G.h.R., Zanganeh Shahraki, S., Sauri, D., Borna, R., 2010b. Urban Sprawl and Climatic Changes in Tehran. Iran. J. Environ. Health. Sci. Eng. 7, 43-52.

Roshan, Gh.R., Khoshakh Lagh, F., Azizi, Gh., Mohammadi, H., 2011. Simulation of temperature changes in Iran under the atmosphere carbon dioxide duplication condition, Iran. J. Environ. Health. Sci. Eng. 9, 139-152.

Sanchez, P.A., 2000. Linking climate change research with food security and poverty reduction in the tropics. Agric. Ecosys. Environ. 82, 371-383.

Shakoor, A., 2011. The Simulation of the Impact of Global Warming on the Evaporation and Perspiration on arid of Iran (Case Study of Tabas). Australian J. Basic. and Appl. Sci. 11, 935-942.

Tubiello, F.N., Rosenzweig, C., Goldberg, R.A., Jagtap, S., Jones, J.W., 2002. Effects of climate change on US crop production: simulation results using two different GCM scenarios. Part I: wheat, potato, maize, and citrus. Clim. Res. 20, 259-270.

Türkes, M., Sümer, U.M., 2004. Spatial and temporal patterns of trends and variability in diurnal temperature ranges in Turkey. Theor. Appl. Clim. 77, 195-227.

Wigley, T.M.L., 2008. MAGICC/SCENGEN User Manual (downloaded from http://www.cgd.ucar.edu/cas/wigley/magicc/).

Wigley, T.M.L., 1995. MAGICC and SCENGEN Integrated models for estimating regional climate change in response to anthropogenic emissions. In: Zverver, S., Van Rompaey, RSAR, Kok MTJ, Berk MM (Eds.), Climate Change Research: Evaluation and Policy Implications, Elsevier, Amsterdam, 1504p.

Wolf, J., Van Diepen, C.A., 1995. Effects of climate change on yield potential of wheat and maize crops in the European Union. Stud. Environ. Sci. 65, 745-750.

Wu, D., Yu, Q., Lu, C., Hengsdijk, H., 2006. Quantifying production potentials of winter wheat in the North China Plain. Europ. J. Agron. 24, 226-235.

Yang, J.C., Zhang, J.H., 2006. Grain filling of cereals under soil drying. New. Phyt. 169, 223-236.

Yano, T., Aydin, M., Haraguchi, T., 2007. Impact of climate change on irrigation demand and crop growth in a Mediterranean environment of Turkey. Sensors. 7, 2297-2315.

Zhang, X., Aguilar, E., Sensoy, S., Melkonyan, H., Tagiyeva, U., Ahmed, N., Kutaladze, N., Rahimzadeh, F., Taghipour, A., Hantosh, T.H., Albert, P., Semawi, M., Karam Ali M., Halal Said Al-Shabibi, M., Al-Oulan, Z., Zatari, T., Al Dean Khelet, I., Hamoud, S., Sagir, R., Demircan, M., Eken, M., Adiguzel, M., Alexander, L., Peterson, T.C., Wallis, T., 2005. Trends in Middle East climate extreme indices from 1950-2003. J. Geophys. Res. 110, D22104.