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Climatic Changes of Khorasan, North-East of Iran, During 1950-2004

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Abstract: The objective of this study was to evaluate the trends in historical temperature and precipitation measurements of Khorasan, Northeast of Iran. The selected sites included Bojnord (37°28′ N, 57°19′ E and 1091 m asl), Mashhad (36°16′ N, 59°38′ E and 999.2 m asl) and Birjand (32°52′ N, 59°12′ E and 1491 m asl). Linear regression analyses were used to determine the trends (slopes) in environmental variables, including monthly and yearly values of precipitation and maximum and minimum temperatures, over the years. While a clear detection of a warming trend as a consequence of greenhouse effect was difficult, the following results were obtained. Minimum temperature (0.29°C/decade) at Bojnord and both minimum (0.45°C/decade) and maximum (0.24°C/decade) temperatures at Mashhad indicated significant positive trend. The positive trend for minimum temperature at Bojnord and Mashhad could be ascribed to greenhouse effect. In Mashhad, vast urbanization and industrialization during the past decades was considered as another reason for positive trend in minimum as well as maximum temperature. At Birjand, however, the opposite was observed and negative trends were detected for both minimum (-0.23°C/decade) and maximum (-0.26°C/decade) temperatures probably as a result of aerosols production due to prolonged natural drought in the adjacent province, Sistan and Baluchestan, during the past decades. There was not a considerable trend in precipitation in monthly or yearly scales.

Key words: Climate change, environment, temperature, Iran, Khorasan

INTRODUCTION

Carbon dioxide concentration in the atmosphere has increased from about 280 ppm before the industrial revolution to about 360 ppm today (Schneider, 1989). Rising concentrations of this gas, as well as other greenhouse gases, could cause global climatic and environmental changes through absorption of long-wave radiation from the Earth's surface (Houghton *et al*., 1996). Increase of carbon dioxide in the atmosphere could cause global warming and changes in temporal and spatial distribution of precipitation (McCabe and Wolock, 2002; Molua, 2006). These changes can have significant impacts on many areas of society, such as energy consumption, agriculture and human comfort (Watson *et al*., 1996).

There is a general agreement among climatologists that the Earth is warming on globe scale but what is happening on regional and season scale is less clear (Cutfoth *et al*., 1999). Therefore, detecting and determination of the direction and magnitude of climate change is a challenging task. There have been numerous studies to identify historical trends in observed temperature and precipitation, for instance, Tao *et al*. (2006), McCabe and Wolock (2002),

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Michaels *et al*. (1998), Liang and Kershaw (1995), Lobel *et al*. (2005), Molua (2006), Qian and Lin (2004), Franke *et al*. (2004), Soule and Yin (1995), Henderson and Muller (1997), Schmith (2001) and Timbal (2004).

So far, no similar studies have been conducted for Khorasan region in the North-East of Iran. Therefore, the objective of this study was to evaluate the trends in historical temperature and precipitation measurements of Khorasan.

MATERIALS AND METHODS

Khorasan has an area of 23800 km^2. Three climate stations with long-term and reliable weather data were selected for the study to represent a large geographical area in Khorasan. The selected sites included Bojnord (37°28′ N, 57°19′ E and 1091 m asl), Mashhad (36°16′ N, 59°38′ E and 999.2 m asl) and Birjand (32°52′ N, 59°12′ E and 1491 m asl) (Fig. 1). The climatic characteristics of the locations represent cold arid climates. Mean annual temperature is 13.2°C for Bojnord, 14.0°C for Mashhad and 16.4°C for Birjand. Total average annual rainfall is 266 mm for Bojnord, 258 mm for Mashhad and 174 mm for Birjand. Weather data of 1977-2004 for Bojnord, 1951-2000 for Mashhad and 1955-2000 for Birjand were available that included precipitation and maximum and minimum temperatures.

Linear regression analyses were used to determine the trends (slopes) in climatic/environmental variables over the years as:

$$y = a + b x$$

where, y is the climatic/environmental variable, x the year, b the trend (slope of the regression) and a the regression intercept. The singe and value of the slope indicate the direction and the magnitude of change in the climatic/environmental variable under consideration. The p-values on the slopes were used to test whether observed changes were significantly different from 0. Regression analyses were performed with the Statistical Analysis System (SAS, 1989). Climatic/environmental variables that were evaluated were monthly and yearly values of precipitation and maximum and minimum temperatures.

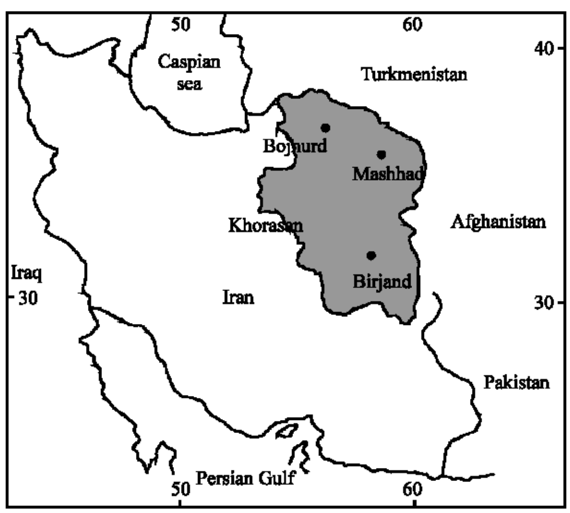

Fig. 1: Locations of the selected sites used in this study

RESULTS

At Bojnord significant increase was observed for minimum temperature in the months August and September (Table 1). The annual average minimum temperature increased significantly by 0.29°C/decade (Fig. 2). Therefore, to 2004, the average minimum temperature has increased by about 1°C since 1977. Maximum temperature showed no significant difference in monthly or yearly scales except for maximum temperature of July that a significant negative trend (-0.75°C/decade) was detected (Table 1). There was not any significant trend in monthly or annual precipitation in this location.

At Mashhad, significant warming trends was found for both minimum temperature and maximum temperature in 9 and 5 of the 12 months, respectively (Table 2). For minimum temperature, the trends varied from 0.29 to 0.68°C/decade. For maximum temperature, these values ranged from 0.21 to 0.65°C/decade. At this location, average yearly values of minimum and maximum temperatures have increased by 0.45 and 0.24°C/decade, respectively (Fig. 3). Thus, to 2000, annual mean minimum and maximum temperatures have increased by about 2.2 and 1.2°C, respectively, since 1951. Similar to Bojnord, no significant change in monthly or yearly precipitation was detected at Mashhad (Table 2).

Table 1: Trends (slope of the linear regression, b) in monthly and annual minimum and maximum temperatures and precipitation in Bojnurd

	Minimum temperature			Maximum temperature			Precipitation		
Months	M (°C)	b (°C/decade)	Pr	M (°C)	b (°C/decade)	Pr	M (mm)	b (mm/decade)	Pr
Jan.	-3.7	0.66	0.0937	6.1	0.03	0.9629	28.5	-2.00	0.5774
Feb.	-3.1	0.76	0.1462	7.2	0.90	0.2162	31.2	-7.65	0.0914
Mar.	0.9	-0.02	0.9505	12.2	-0.22	0.7046	40.6	0.34	0.5085
Apr.	6.8	-0.34	0.1979	20.2	-1.05	0.0620	33.9	9.41	0.1508
May	10.7	-0.07	0.8182	24.3	-0.09	0.8673	34.1	-9.75	0.1302
Jun.	15.1	-0.013	0.5991	29.8	-0.30	0.4323	9.1	-1.13	0.6371
Jul.	17.8	0.05	0.7985	32.6	**-0.75**	**0.0129**	9.6	1.23	0.7727
Aug.	16.5	**0.67**	**0.0374**	31.8	0.37	0.2746	6.4	0.57	0.8239
Sep.	12.3	**0.59**	**0.0288**	28.1	-0.39	0.2313	10.1	1.23	0.7969
Oct.	6.3	0.53	0.1570	20.8	0.50	0.3309	14.8	-2.14	0.3927
Nov.	2.2	0.44	0.1722	14.4	-0.41	0.5119	23.6	1.48	0.7338
Dec.	-1.4	0.17	0.7057	8.9	-0.12	0.8306	24.5	-3.28	0.4693
Annual	6.7	**0.29**	**0.0146**	19.7	-0.10	0.6202	266.4	-1.75	0.9224

M = Mean value, b = Trend, Pr = Significance level, Significant cases are indicated as bold

Table 2: Trends (slope of the linear regression, b) in monthly and annual minimum and maximum temperatures and precipitation in Mashhad

	Minimum temperature			Maximum temperature			Precipitation		
Months	M (°C)	b (°C/decade)	Pr	M (°C)	b (°C/decade)	Pr	M (mm)	b (mm/decade)	Pr
Jan.	-4.1	0.35	0.2269	7.1	0.05	0.8854	33.1	2.11	0.3497
Feb.	-2.3	0.07	0.8317	8.9	-0.08	0.8367	37.1	4.66	0.0579
Mar.	2.4	0.03	0.8393	13.6	0.04	0.8716	55.8	0.42	0.8747
Apr.	8.1	**0.35**	**0.0029**	20.7	**0.65**	**0.0021**	47.7	-2.03	0.4846
May	12.0	**0.29**	**0.0177**	26.5	0.14	0.4404	27.1	-0.58	0.8173
Jun.	16.0	**0.64**	**<0.0001**	32.1	**0.35**	**0.0058**	4.4	1.03	0.2080
Jul.	18.3	**0.55**	**0.0002**	34.3	**0.21**	**0.0402**	0.8	0.11	0.5496
Aug.	16.0	**0.63**	**0.0005**	32.9	**0.28**	**0.0252**	0.7	0.27	0.0975
Sep.	11.2	**0.56**	**0.0012**	28.8	**0.24**	**0.0431**	1.9	0.79	0.0946
Oct.	5.9	**0.50**	**0.0110**	22.1	0.15	0.4135	9.3	-0.11	0.9310
Nov.	1.5	**0.68**	**0.0032**	15.3	0.49	0.0757	15.3	-1.31	0.3851
Dec.	-2.0	**0.64**	**0.0054**	9.7	0.41	0.1259	24.3	1.71	0.3340
Annual	6.9	**0.45**	**0.0001**	21.0	**0.24**	**0.0096**	257.5	6.95	0.3310

M = Mean value, b = Trend, Pr = Significance level, Significant cases are indicated as bold

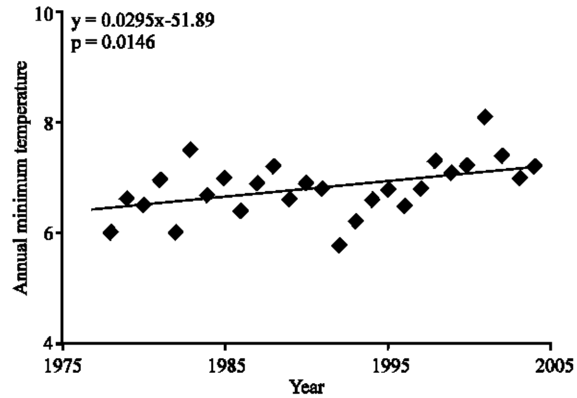

Fig. 2: Trend in annual minimum temperature (°C) at Bojnurd

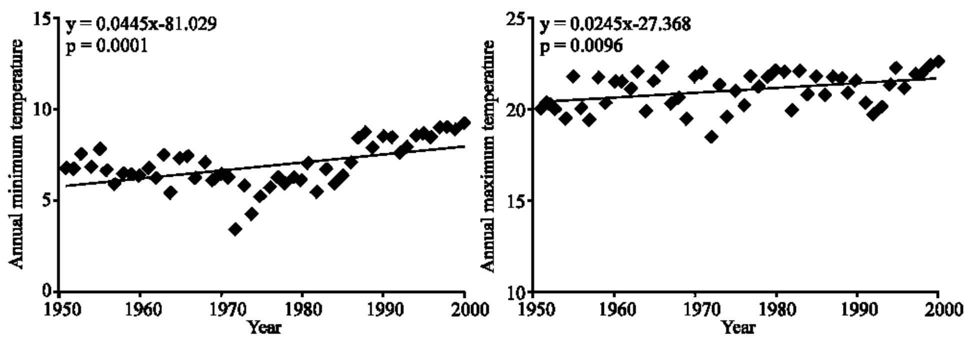

Fig. 3: Trends in annual minimum and maximum temperatures (°C) at Mashhad

Table 3: Trends (slope of the linear regression, b) in monthly and annual minimum and maximum temperatures and precipitation in Birjand

	Minimum temperature			Maximum temperature			Precipitation		
Month	M (°C)	b (°C/decade)	Pr	M (°C)	b (°C/decade)	Pr	M (mm)	b (mm/decade)	Pr
Jan.	-2.2	**-0.43**	**0.0210**	11.0	-0.25	0.3636	32.5	-2.96	0.2115
Feb.	-0.2	-0.40	0.0775	13.3	-0.50	0.0892	31.8	3.05	0.2324
Mar.	4.3	**-0.65**	**0.0014**	18.3	**-0.91**	**0.0009**	39.1	**6.19**	**0.0296**
Apr.	9.5	-0.17	0.2173	24.5	-0.03	0.9035	30.3	**-5.60**	**0.0454**
May	13.6	-0.12	0.4537	30.3	-0.20	0.3709	8.4	-2.95	0.0876
Jun.	17.8	0.02	0.9009	34.9	-0.21	0.1674	0.6	0.17	0.2871
Jul.	19.7	-0.25	0.0882	35.7	**-0.40**	**0.0047**	0.2	0.02	0.7949
Aug.	17.1	-0.21	0.2378	34.4	-0.25	0.1919	0.1	0.01	0.8737
Sep.	12.3	-0.32	0.1182	31.8	-0.25	0.1672	0.3	0.30	0.0698
Oct.	7.1	-0.21	0.3657	26.4	**-0.46**	**0.0063**	2.6	0.59	0.2326
Nov.	2.2	0.004	0.9835	19.5	0.02	0.9426	7.8	-0.55	0.6597
Dec.	-1.0	-0.05	0.8119	13.6	0.19	0.4627	20.9	2.01	0.3043
Annual	8.3	**-0.23**	**0.0162**	24.5	**-0.26**	**0.0169**	174.0	0.88	0.9003

M = Mean value, b = Trend, Pr = Significance level, Significant cases are indicated as bold

At Birjand, negative trends were observed for minimum and maximum temperatures for nearly all months of the year as indicated in Table 3. However, these trends were only significant for minimum temperature of January, March and for maximum temperature of March, July and October. In annual scale, significant decrease was found for minimum temperature by -0.23°C/decade and for

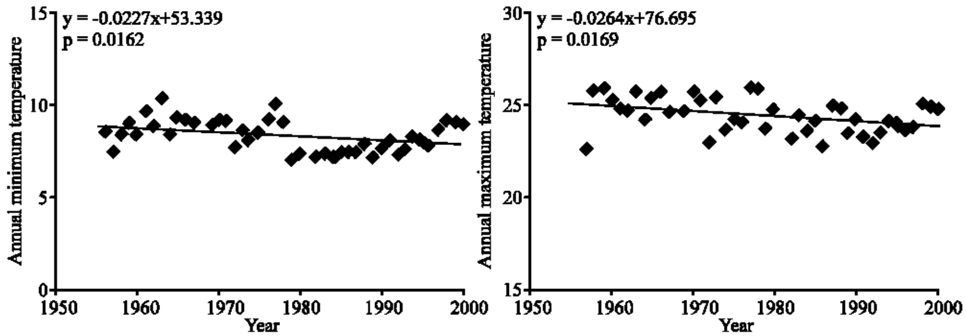

Fig. 4: Trends in annual minimum and maximum temperature (°C) at Birjand

maximum temperature by -0.26°C/decade (Fig. 4), corresponding to 1 and 1.2°C decrease since 1955 to 2000. At this location, significant positive trend was observed for March precipitation (6.2 mm/decade), but significant negative trend was detected for April precipitation (-5.6 mm/decade) (Table 3).

DISCUSSION

Our selected sites are located in various geographical zones of Khorasan and consequently showed diverse climate change patterns. At Bojnord, only minimum temperature showed significant positive trend. At Mashhad both minimum and maximum temperatures indicated significant positive trend. However, at Birjand the opposite was observed; negative trends were detected in both minimum and maximum temperatures. There was not a considerable trend in precipitation in monthly or yearly scales.

Evaluation of past changes in climatic/environmental parameters around the world have resulted in similar results. Kukla and Karl (1993) analyzed data from several countries, including the USA, Canada, China, Russia, Australia, Sudan, Japan, Denmark, Finland, Pakistan, South Africa and some European countries and reported an increase in minimum temperature with exception of the Eastern coast of North America, where it decreased. Skinner and Gullett (1993) reported significant increases in both minimum and maximum temperature during spring for the prairie region of Canada from 1950 to 1989. However, significant decreases in both maximum and minimum temperature have occurred during winter and autumn in the Atlantic region. Bootsma (1994) studying long-term weather trends at five locations across Canada found that detection of climatic warming was difficult because of the extreme variability of climatic attributes. Cutfoth *et al.* (1999) evaluated climate change in the semiarid prairie of Southwestern Saskatchewan and reported that winter and spring maximum and minimum temperatures have warmed but the date of the last spring frost has not gotten earlier with time. Pathak *et al.* (2003), studying in the Indo-Gangetic Plains, found a negative trend at three sites, whereas six sites showed a positive trend. However, they reported stable maximum temperature over years.

Michaels *et al.* (1998) presented the data that argue against the proposition that temperature have become more variable as global temperature has changed in the USA. Lobel *et al.* (2005) reported a cooling trend in nighttime temperature in Mexico. However, Molua (2006) reported strong positive temperature trends for the months of July, August and September in Cameroon during 1960-2000 periods. Qian and Lin (2004) observed trends of increasing warm days in the upper-middle Yellow River valley and other regions such as along the coast of South China, while there are decreasing trends scattered in the central part of East China. Franke *et al.* (2004) reported increase in temperature in all seasons and especially in winter in Saxony, Eastern Germany. Henderson and Muller (1997) in their study of extreme temperature days in the South-central USA reported that over this century there is a long-term trend toward more frequent cold days in all seasons. However this trend may be reversing in the past decade. Tao *et al*. (2006) evaluated trends in climatic parameters in five sites in China and found significant warming trends at most of the investigated sites.

In the case of precipitation, Karl and Heim (1990) found significant shifts toward wetter conditions nationally since the mid 1930s but no significant trends when using data from the entire study period (1895 to 1989). Soule and Yin (1995) found that mean trends for the USA nation as a whole are positive for the 95, 50 and 30 year time series, but switch to negative for the most recent 15 year time series. They conclude that the perception of climate changing toward either a wetter or drier regime is thus partially a function of temporal scaling. Franke *et al*. (2004) found marked decrease in summer rainfall (-10 to -30%) but significant increase in winter precipitation in Saxony, Germany. Molua (2006) reported an increasing dryness and drought in Cameroon.

Positive trend found in this study for minimum temperature at Bojnord and Mashhad might be, at least in part, due to greenhouse effect, while other probable reasons for increase in minimum temperature are (Kukla and Karl, 1993): (1) an increase in natural and anthropogenic clouds, (2) haze from cities, factories and burning fields and forests, (3) vapor trails of high altitude aircraft, (4) irrigation that keeps the soil surface warmer at night, (5) anthropogenic greenhouse gases and (6) warming of the urban zones, which keeps the night temperature high. In Mashhad, vast urbanization and industrialization during the past decades can be considered as a reason of positive trend in minimum as well as maximum temperature. Negative trend in minimum and maximum temperatures observed in this study for Birjand can be ascribed to aerosols production as a result of prolonged natural drought in the adjacent province, Sistan and Baluchestan, during the past decades. Emissions that increase the percentage of incoming radiant energy reflected back into space result in cooling effect.

In studies like the present study detection of a warming trend as a consequence of greenhouse effect is difficult because of several reasons. First, climate is highly variable and continually changing. Second, the driving forces behind these changes have both natural and human origins (Schneider, 1994) with both warming and cooling effect. Third, some phenomena such as El Niño/Southern Oscillation cause considerable short-term climate variability (Soltani and Gholipoor, 2006) but do not result in long-term climate change. Forth, the duration of climate data set (length of record) may have a profound influence on conclusions reached regarding climate change (Cutfoth *et al*., 1999).

Overall, a warming trend was found for temperature that could be ascribed to greenhouse effect. However, there was not a considerable trend in precipitation in monthly or yearly scales.

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