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Linkage between Climate Change and Extreme Events in Iran

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Abstract

In recent years, interest in climatic extreme events (droughts, floods and heat waves) has been growing not only due to their direct impact on many socio-economic sectors, but also as climate change indicators. In this study, the behavior of extreme events is investigated using Extreme Climate Index Software (ECIS) package. The trend analysis of extreme indices is applied to daily series of temperature and precipitation observations from 16 synoptic stations over Iran in the period 1951-2003. Results show that the number of very warm days (T40) has increased while the number of very cool days (ID) has decreased and so the return period (Ťret) of cold extreme indices increased and the Tret of warm extreme indices decreased. Changes in total and extreme precipitation indices vary, depending upon geographic location. Symmetric warming in the tails of most indices is seen overall. On the basis of a systematic analysis of observed changes in indices of climate extremes, a significant proportion of Iran is increasingly affected by a significant change in extreme indices in the ~50-yr study period.

Key words: Linkage, Climate change, Extreme events, Return period, Iran

ارتباط بین تغییر اقلیم و رویدادهای حدی

فرحناز تقوی

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چکیده

در سال‌های اخیر توجه به رویدادهای حدی (خشکسالی‌ها، سیل‌ها و امواج شدید گرمایی)، نه‌تنها به علت پیامدهای اقتصادی، اجتماعی بلکه به‌منزلهٔ نشانگرهای تغییر اقلیم، اهمیت زیادی پیدا کرده است. در این تحقیق برای یافتن ارتباط بین تغییر اقلیم و رویدادهای حدی، رفتار و فراوانی رویدادهای حدی با استفاده از شاخص‌هایی در بسته نرم‌افزاری بنام شاخص‌های اقلیمی حدی (Extreme Climate Index Software, ECIS) بررسی شده است. دربسته نرم‌افزاری ECIS روند شاخص‌ها براساس داده‌های روزانه دما و بارش ۱۶ ایستگاه همدیدی (شاخص نواحی اقلیمی ایران) در دوره آماری۲۰۰۳-۱۹۵۱ محاسبه شده است. در نهایت نقشه‌های روند شاخص‌های حدی در ایران تهیه شد. نتایج تحقیق نشان می‌دهد که روند کاهشی شاخص‌های حدی سرد FD وروند افزایشی در شاخص‌های حدی گرم مانند T40 در همه نواحی اقلیمی ایران به‌جز در ناحیه شمال غرب وجود دارد و گرمایش متقارن در بیشتر دنباله سری‌های زمانی شاخص‌های حدی به‌جز در دو ایستگاه همدان و ارومیه وجود دارد .همچنین نتایج مبین افزایش قابل توجهی در تعداد روزها و شب‌های خیلی گرم و کاهش در دامنه دمایی حدهای سالانه است و همین امر سبب کوتاه شدن دوره بازگشت شاخص‌های حدی گرم مانند SU، T40 و بلندترشدن دوره بازگشت شاخص‌های حدی سرد FD و ID شده است اما روند شاخص‌های حدی بارش تغییرات اندکی را نشان می‌دهد. این نتایج فراوانی رویدادهای حدی اقلیمی مانند خشک‌سالی و طولانی

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شدن امواج گرم در اکثر نواحی اقلیمی ایران را تایید می‌کند. به‌طورکلی براساس نتایج تغییر در روند شاخص‌های حدی در ایران بارز است و نشانه‌های روشنی از تغییر اقلیم وجود دارد.

واژه‌های کلیدی: ارتباط، تغییر اقلیم، رویدادهای حدی، روند، دوره بازگشت، ایران

1 INTRODUCTION

Extreme weather events (droughts, floods and heat waves) are a matter of great topical importance and interest in a variety of environmental and social situations. Studies show that there are various levels of certainty associated with the linkages between climate change and extreme weather events. One of the anticipated effects of climate change is the possible increase in both frequency and intensity of extreme weather events. Increase of the average temperature of the earth over the 20th century (0.4-0.8ºc) may fuel interactions between the ocean and atmosphere that will amplify the frequency and intensity of extreme weather events (Tompkins, 2002).

Because ecosystems and the physical infrastructure of human societies are tuned to normal conditions, they are generally poorly equipped to cope with extreme events. As a result, changes in the occurrence of extreme events (henceforth Xevents) can often have far greater detrimental impacts on ecosystems and human societies than a change in average climate conditions.

Studies indicate an increase extreme warm events in the past decades, especially since 1983 (WMO, 1997; Easterling et al., 2000). However, this increase in temperature extremes is different from region to region. Bonsal et al. (2001) performed an analysis on the spatial and temporal variability of extreme temperature in Canada for the period of 1950–1998 and found great regional and seasonal differences. Meanwhile, public awareness of Xevents has risen sharply in recent years partly because of tremendous concern over the catastrophic nature of floods, droughts, storms and heat waves or cold spells (Beniston and Stephenson, 2004).

Temperature extremes exert considerable influences not only on processes in nature but also on different aspects of socio-economic activities. More and more research results indicate that extreme high temperatures and prolonged heat waves can damage agricultural production, increase energy and water consumption and also exert negative impact on human well-being and even on human health (Karl and Easterling, 1999; Kunkel et al., 1999; Easterling et al., 2000; Nasrallah et al., 2004). The changes of spatial and temporal distribution of extreme temperature and precipitation have been receiving increased attention in the last few years (Jones et al., 1999; Zhai et al., 1999; Zhang et al., 2001; Klien Tank and Konnen, 2003; Haylock and Nicholls, 2000; India Brunet and Lopez Bonilo, 2001; Collins et al., 2000; Goodes, 2004; Frich et al., 2002; Yan et al., 2002).

The report of the worlds largest reinsurance firm (Munich Re., 2005) indicates that the weather-related disasters have a positive trend from about 1 event in the 1950s to about 5 in recent decades, while geophysically caused disasters (earthquakes, tsunamis, volcano eruptions) have increased from 1 to close to 2 in the same time and since the 1980s there has been a particularly large increase in the frequency and magnitude of disasters. Weather related disasters therefore are the major contributor to increasing losses due to natural disasters. Therefore, it is very important to understand the spatial and temporal variability of extreme temperature and precipitation. Xevents take many forms and a variety of techniques are useful for determining their statistical properties. In this study, the behavior of Xevents as an indicator of climate change is investigated using Extreme Climate Index Software (ECIS) package.

2 DATA AND METHOD

To describe accurately the spatial and temporal characteristics of daily and extreme climate variables, long –period time series of reliable and homogenous daily data are required. Therefore, a method to analyze the spatial and temporal trend of extreme indices is applied using Extreme Climate Index Software (ECIS) package. (The ECIS package includes a code under Matlab programming which is introduced to detect climate change in Iran (Taghavi, 2005).

Extreme indices are selected from the list of climate change indices recommended by the Research Program on Climate Variability and Predictability (WMO-CCl/CLIVAR). A list of over 50 climate change indices is available on line at http://www.knmi.nl/samenw/eca (Peterson et al., 2001). A set of 26 climate change indices are used in the present study. Most of the indices are defined in terms of counts of days crossing thresholds, either absolute (fixed) thresholds or percentile (variables) thresholds. Of this set, 16 indices refer to temperature and 10 to precipitation (Table 1) and the indices are expressed in annual values. The temperature indices describe cold extremes as well as warm extremes. The precipitation indices describe wet extremes and percentile thresholds. Annual day-count indices based on percentile thresholds are expressions of anomalies relative to the local climate from the observed station series in the period 1961-1990. Daily maximum, minimum and mean temperature and precipitation data series from 16 synoptic stations in Iran are collected for use in the analysis in the period 1951–2003.

Table 1. Indices of daily Temperature and Precipitation Extremes.

INDEX	Description	Formula
FD	Frost Day	Number of days(per year)with Tmin<0
SU	Summer Day	Number of days(per year)with Tmax>25
ID	Icing Day	Number of days(per year)with Tmax<0
T40	Tmax >=40	Number of days(per year)with Tmax>=40
MIN21	TMIN>21	Number of days(per year)with Tmin>21
HWDI	Heat Wave Duration	Number of days(per year)with Tmax>5+mean
CWDI	Cold Wave Duration	Number of days(per year)with Tmin>-5+mean
TR	Tropical Day	Number of days(per year)with Tmin>20
RR1	Rain>=1mm	Number of days(per year)with Rain>=1mm
RR5	Rain>=5mm	Number of days(per year)with Rain>=5mm
RR10	Rain>=10mm	Number of days(per year)with Rain>=10mm
RR20	Rain>=20mm	Number of days(per year)with Rain>=20mm
CDD	Cold Degree- Day	sum of degree- days(per year)with Tmean-21
HDD	Heat Degree- Day	sum of degree- days(per year)with 18-Tmean
GDD	Growing Degree- Day	sum of degree- days(per year)with Tmean>=5.5
SDII	Simple Daily Intensity index	Annual pericipitation/no. of wet days
ETR	Extreme Temperature Range	Difference:Tmax-Tmin
P10	10th percentile Tmin	Number of days withTmin<10th percentile
P90	90th percentile Tmin	Number of days(per year)with Tmin>90th percentile
PE10	10th percentile Tmax	Number of days(per year)with Tmax>10th percentile
PE90	90th percentile Tmax	Number of days(per year)with Tmax>90th percentile
PER10	10th Percentile RR1	Number of days(per year)with Rain>90th percentileRR1
PER901	90th Percentile RR1	Number of days(per year)with Rain>90th percentile RR1
PER95	95th Percentile RR1	Number of days(per year)with Rain>95th percentile RR1
WD	Wet Day	Number of days(per year)with Rain
DD	Dry Day	Number of days(per year)without Rain

Selected stations are representative of the climatic regions on the basis of the latest climatic classification using the factor analysis method (Heydari and Alijani, 2000). In this study, first the daily data of synoptic stations with standard format are extracted and decoded in the Homogeny Data program and then the missing values are replaced by the Gap subroutine using the ECIS package. The meteorological stations with missing data exceeding 1 year are excluded from the data set, which results in 16 useful meteorological stations in the current study. The four stations have missing data in 1-3 months and 6 stations have missing data in 1-7 days. In the first case the missing data are completed by their neighboring stations through the simple linear regression method with regression correlation coefficient R>0.9. In the second case, the missing data are filled in by the average value of its neighboring days. Output file is the matrix of daily data of synoptic stations in the period 1951-2003. This matrix includes m(daily data) rows from 1 January 1951 to 31 December 2003 and 7 columns including year, month, day, daily precipitation, daily maximum temperature, daily minimum temperature and daily mean temperature, respectively. In the Statistic program, the statistical characteristics of data such as mean, maximum, minimum and percentiles (10, 90, and 95) of the variables are calculated and then the return period of indices is calculated. For the day –count indices, the corresponding mean return period (Ťret) is given by:

$$\check{T}ret=365 /\hat{I}$$

Ťret is expressed in days and the value Î is the mean of the indices. Finally, the defined indices and their trends are estimated by Index program. The ECIS allows the user to calculate trends of extreme climate indices for different time periods and for multiple stations. The final output of ECIS consists of an Excel file which includes longitude, latitude, the trend of indices and the return period of indices. The results can then be displayed on a map using the user's software of choice. In current study, the Kriging method is used by the Arc view software.

3 RESULTS

Table 2 lists the name of station, X (longitude), Y (latitude) and the values of annual trends of the 26 indices over the period 1951-2003.

Results in Table 2 show different trends in extreme indices in the ~50-yr study period. For example, the cold extremes FD (Frost days) and ID (Icing days) show a pronounced decreasing trend. On the other hand the warm extreme indices such as SU (summer days) and T40 (days with Tmax>=40°c) have an increasing trend.

Besides, increases in daily temperature lead to an increase in prolonged heat waves and length of growth. On average, the MIN21 (days with Tmin>21°c) index, had an increasing trend and the ETR (Extreme Temperature Range) index had a decreasing trend over Iran in the past 50 years.

Indices based on the count of days crossing certain fixed thresholds (e.g. the 0ºc threshold as used in Frost day's index) can also be related to observe impacts and these indices are more suitable in climate change studies. However, changes in temperature can be very much influenced by changes in other climate factors as well .The disappearance of snow cover, for example greatly enhances daytime surface warming and hence midday maximum temperature .

The analysis of daily precipitation observations shows that the extreme precipitation indices such as RR1 and RR10 show no significant trends and the maximum negative trend in RR10 is seen in Anzali station (moist climatic region).

The maximum negative trend in RR1 and RR5 is seen in Orumieh station (cold climatic region) and the greatest positive and negative trends in extreme precipitation indices such as PER10 (days with rain >10th percentile RR1) are seen in Yazd and Tehran stations.

The PE90 (days with Tmin >90th percentile) index has a significant positive trend in Shiraz with a value +0.71.

Table 2. Trend in Extreme Indices in Iran in the period 1951-2003.

NAME	X	Y	FD	P10	CWDI	HWDI	P90	SU	ID
ABADAN	48.25	30.37	-0.2991	-0.0158	-0.3209	0.0251	0.6698	0.0612	0.0000
AHWAZ	48.67	31.33	-0.0650	-0.0192	-0.6700	0.2270	1.5400	0.1690	0.0000
ANZALI	49.47	37.47	-0.2000	-0.1102	-0.1630	0.2650	0.6400	-0.2700	-0.0009
BABOLSAR	52.65	36.72	-0.1638	-0.0896	-0.4710	0.2430	0.3688	0.4172	-0.0006
BUSHEHR	50.83	28.98	-0.0031	-0.0002	-0.4995	0.1765	1.1325	0.1586	0.0000
HAMEDAN	48.72	35.20	0.6902	0.6571	0.9558	0.5531	-0.0015	0.4300	0.1570
KERMAN	56.97	30.25	0.0971	0.1097	0.1136	0.1210	0.0151	0.1898	0.0071
KERMANSHAH	47.12	34.28	-0.5520	-0.4060	-0.7220	0.3000	0.0158	0.2820	-0.0240
MASHHAD	59.63	36.27	-0.6706	-0.6810	-0.8420	0.3770	0.0190	0.3380	-0.0490
ORUMIEH	45.08	37.53	0.4900	0.4748	0.8238	-0.2041	0.0000	-0.2608	-0.0041
SHAHROUD	54.95	36.42	-0.4623	-0.4281	-0.2515	0.3104	0.1819	0.3359	0.0041
SHIRAZ	52.53	29.60	-0.6155	-0.5763	-0.9088	0.0955	0.2137	0.2691	-0.0010
TABRIZ	46.28	38.08	-0.4387	-0.4301	-0.6365	0.1457	0.1044	0.2090	-0.1254
TEHRAN	51.32	35.68	-0.8430	-0.6767	-0.7757	0.1605	1.0460	0.2054	-0.0230
YAZD	54.40	31.90	-0.2769	-0.2633	-0.2629	0.4620	0.4827	0.4182	-0.0006
ZAHEDAN	60.88	29.47	-0.1867	-0.1719	-0.3206	-0.0371	0.1596	0.1532	0.0008

NAME	T40	MIN21	HDD	CDD	ETR	TR	RR1	RR5	RR10
ABADAN	0.1945	0.6462	-7.2640	7.2000	-0.0120	0.6100	0.0110	0.0373	0.0131
AHWAZ	0.1980	2.3428	-15.4000	14.9000	0.0540	1.7200	0.0820	0.0383	0.0544
ANZALI	0.0000	1.1960	0.5400	-1.7700	-0.0640	0.3250	-0.1000	-0.1100	-0.1300
BABOLSAR	-0.0005	0.8459	-9.2100	9.2200	-0.0110	0.1300	-0.0728	-0.0020	0.0122
BUSHEHR	-0.0966	0.9236	-8.7710	8.5500	0.0350	1.0000	0.0859	0.0085	0.0137
HAMEDAN	0.0016	0.0212	8.2914	10.4794	0.0630	0.0000	0.1140	0.0367	0.0099
KERMAN	-0.0181	-0.0520	0.3641	-0.4802	0.0160	0.0060	-0.1730	-0.0960	-0.0170
KERMANSH AH	0.1935	0.0800	-10.7500	10.3200	-0.0120	0.0061	-0.0630	0.0170	-0.0010
MASHHAD	0.0266	0.3740	-14.7400	14.8010	0.0210	0.0002	-0.0700	0.0161	0.0350
ORUMIEH	0.0000	0.0070	12.9000	-13.7780	0.0130	0.0000	-0.1746	-0.1423	-0.0761
SHAHROUD	0.0123	0.7136	-7.3720	6.1910	-0.0290	0.1000	0.0380	0.0568	0.0261
SHIRAZ	0.2120	0.8905	-13.7200	13.8400	-0.0360	0.0900	-0.0482	0.0151	0.0075
TABRIZ	-0.0064	0.4239	-10.7500	10.6300	-0.0230	0.0470	-0.3124	-0.0817	-0.0594
TEHRAN	0.0263	1.1816	-14.1490	14.1550	-0.0570	0.8200	-0.0210	0.0120	0.0079
YAZD	0.0447	0.7065	-9.0620	7.9600	-0.0100	0.3600	-0.0401	-0.0189	0.0157
ZAHEDAN	-0.0249	0.4046	-3.8490	3.5030	-0.0220	0.0880	-0.0978	-0.0739	-0.0544

NAME	RR20	PER95	WD	DD	SDII	GDD	PE10	PE90	PER10	PER90
ABADAN	0.0116	0.0482	0.1493	-0.1278	0.0039	0.0310	-0.0080	0.1400	-0.1270	-0.0110
AHWAZ	0.0038	0.0367	0.4173	-0.2440	-0.0422	0.0460	-0.0080	0.2870	-0.2440	0.0820
ANZALI	-0.0800	0.0550	0.3000	0.0900	-0.0800	0.2500	0.2100	-0.0006	0.0920	-0.1570
BABOLSAR	0.0766	-0.0067	0.2698	-0.2711	0.0115	0.0190	-0.1080	-0.0010	-0.2710	-0.0720
BUSHEHR	-0.0060	0.0259	0.3334	-0.2593	-0.1140	0.0120	-0.0010	0.2340	-0.2590	0.0860
HAMEDAN	-0.0222	0.0254	0.4311	0.1047	-0.0270	-0.0140	0.1680	0.2650	0.2980	0.1100
KERMAN	-0.0121	-0.1128	0.0440	-0.0058	-0.0310	0.0700	-0.0370	0.1130	-0.0060	-0.1700
KERMANSHAH	0.0260	-0.0068	0.2700	-0.1250	-0.0167	0.2300	-0.0090	0.5310	-0.1250	-0.0630
MASHHAD	0.0003	-0.0047	0.1664	-0.1857	-0.0057	0.1150	-0.1170	0.2500	-0.1850	-0.0700
ORUMIEH	-0.0146	-0.1390	0.0159	0.2728	-0.0209	-0.0830	0.2540	-0.0370	0.2750	-0.1740
SHAHROUD	0.0129	0.0482	0.1472	0.2464	0.0092	0.2810	0.2030	0.1690	0.2460	0.0380
SHIRAZ	-0.0147	0.0186	0.2001	-0.2384	-0.0622	-0.0010	-0.0660	0.7130	-0.2380	-0.0480
TABRIZ	-0.0316	-0.1246	-0.0630	0.1022	-0.0208	0.1590	-0.0190	0.0650	0.1020	-0.3120
TEHRAN	0.0166	0.0153	0.2922	-0.2905	-0.0109	0.0660	0.0460	0.2600	-0.2900	-0.0210
YAZD	-0.0027	-0.0264	0.1538	0.2147	-0.0150	0.2800	-0.0260	0.5240	0.8110	-0.0130
ZAHEDAN	-0.0292	-0.0941	0.0407	0.0745	-0.0816	0.0610	0.0100	0.0620	0.0740	-0.0970

Based upon data analysis; over all stations the TR (tropical day) index has a positive trend with a maximum value +1.7 in the Ahwaz station (figure 1a).

There is also a significant decrease in cold extreme indices occurring at stations (for example, Tehran) which could be partly due to urbanization. The greatest negative trend in FD index is seen in Tehran station (moderate desert climatic region) with a value -0.84.

In most parts of Iran, except for the northwest region, the FD (Frost day) index has a significantly decreasing trend (figure 1b). This suggests that the increase in the northwest region is due to the increase in both frequency and intensity of precipitation.

In all stations, the number of wet days (WD) has increased with the greatest positive trend seen in Hamedan station (figure 1c).

The cold wave duration index (CWDI) has negative trends in 13 stations and a positive trend in Hamedan and Orumieh stations.

Pronounced negative trend in CWDI is seen in Shiraz station (figure 1d). The warm extremes indices such as T40, SU, CDD (cold degree-days) and GDD (growing degree-days) show increasing trend (figures 2a, 2b, 2c, 2d) but the CDD index has a pronounced negative trend and the cold extreme ID has a small negative trend in Orumieh station (figure 3a).

The analysis of the HDD (heating degree-days) shows different trends. The greatest positive trend in HDD is seen in Ahwaz station (figure 3b). Indices of extreme precipitation such as SDII (simple daily intensity index) and RR20 show minor decreasing trends, however the trend of PER95 (number of days with rain>95th percentile RR1) index in 8 stations is negative and in the other stations have small positive trends (figure 4a, 4b, 4c). In all stations the HWDI (Heatwave duration index) have positive trends (figure 4d).

Changes in extreme indices described in terms of return values of annual extremes are examined in 9 stations which have significant variations. The return values are estimated from the Ťret formula. The analysis of the return values of indices in two periods 1961-1990 and recent decade 1991-2000 indicate that some of the indices such as FD, SU, and WD have significant variations. According to Table3 and Table4, the return periods of FD index increase over many regions as the climate warms and the return periods for the WD decreased but the SU index show no significant difference. For example, the return periods of the FD, WD and SU indices in Tehran are 7 days, 6.27 days and 2.23 days in the standard period (1961-1990) while they are 12 days, 5.99 days and 2.2 days in the decade (1991-2000).

Table 3. The Return Period of extreme indices in the period 1961-1990.

station \ Index	FD	SU	WD
Abadan	202	1.45	12.28
Orumieh	3.25	3.32	4.95
Anzali	40.5	3.36	2.78
Tehran	7	2.23	6.27
Zahedan	6.2	1.74	16.41
Shiraz	6.61	1.94	9.12
Mashhad	3.71	2.37	5.96
Kermanshah	3.96	2.34	5.1
Yazd	6.22	1.84	17.9

Table 4. The Return Period of extreme indices in the period 1991-2000.

station \ Index	FD	SU	WD
Abadan	3650	1.44	10.57
Orumieh	3.28	3.2	5
Anzali	228	3.8	2.71
Tehran	12	2.2	5.99
Zahedan	7.74	1.76	14.03
Shiraz	14.8	1.9	7.44
Mashhad	5.1	2.37	5.14
Kermansha	4.45	2.18	4.7
Yazd	8.5	1.8	14.31

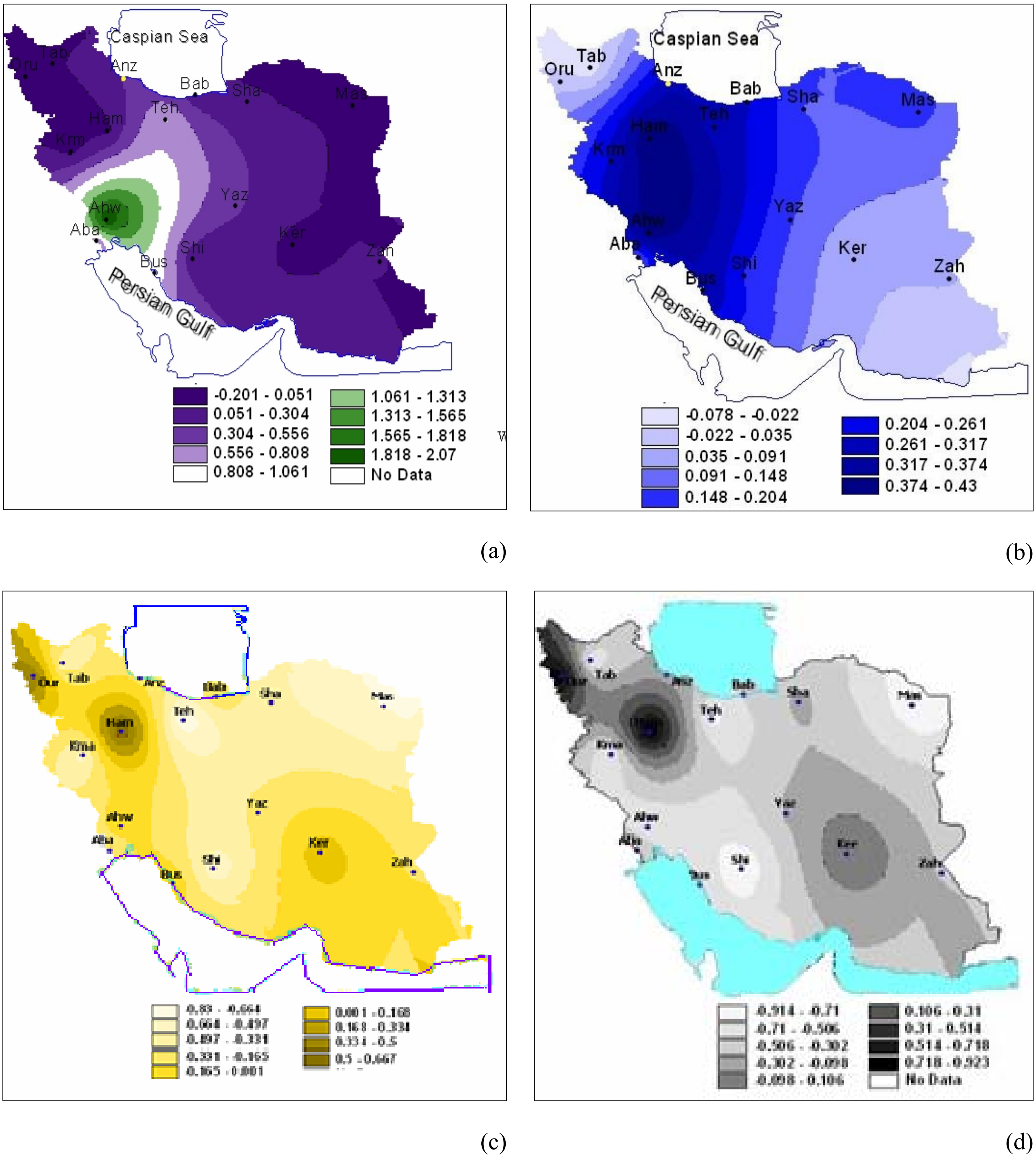

Figure 1. Trend in the annual number of (a) TR index, (b) WD index, (c) FD index and (d) CWDI index in the period 1951-2003 in Iran by Kriging method.

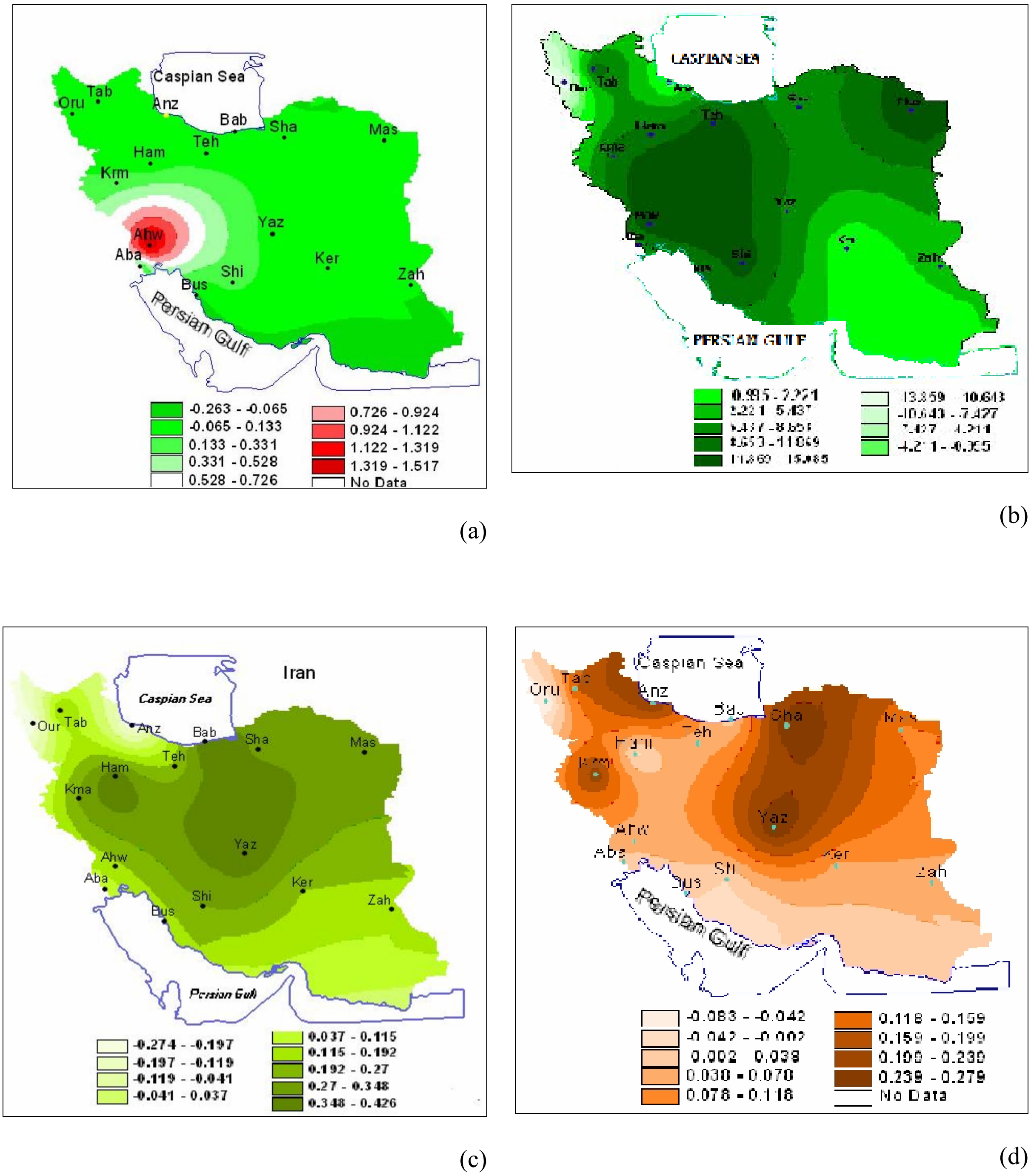

Figure 2. Trend in the annual number of (a) T40 index, (b) CDD index, (c) SU index and (d) GDD index in the period 1951-2003 in Iran by Kriging method.

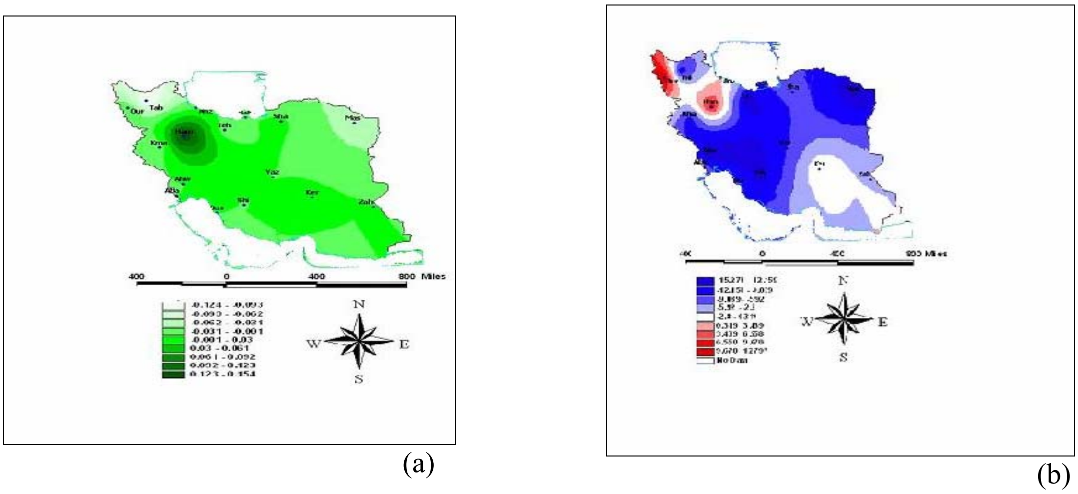

Figure 3. Trend in the annual number of (a) ID index, (b) HDD index in the period 1951-2003 in Iran by Kriging method.

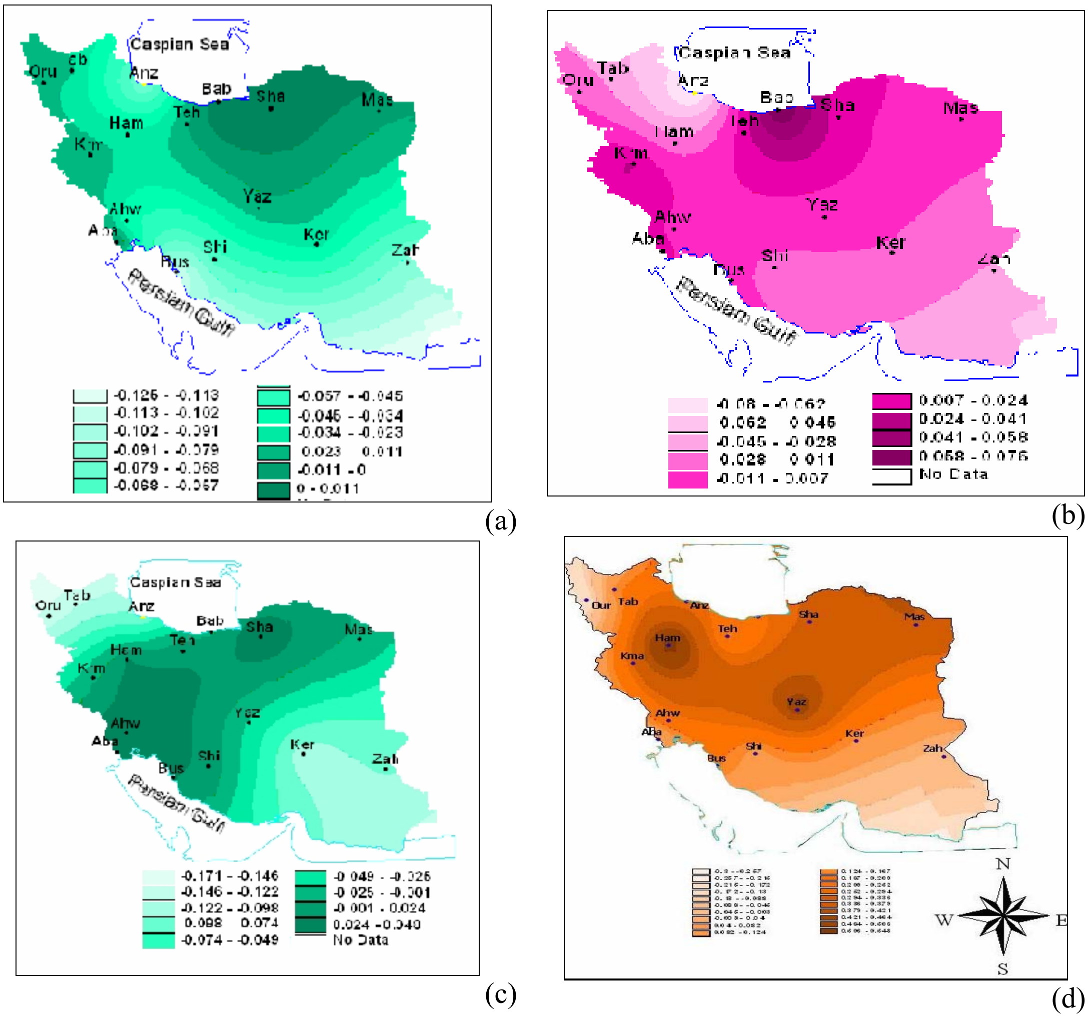

Figure 4. Trend in the annual number of (a) SDII index, (b) RR20 index, (c) PER95 index and (d) HWDI index in the period 1951-2003 in Iran by Kriging method.

4 CONCLUSION

From the results discussed above, it is evident that all of the stations show negative trends in FD index and positive trends in TR index although not always significant for the period 1951-2003 over Iran. Symmetric warming in the tails of the most indices is seen overall and the results demonstrated positive trends in warm extreme indices over most regions of Iran except the northwest stations. Changes in total and extreme precipitation vary depending upon geographic location. Besides, results indicate that the Ťret of cold extremes indices such as FD increased and the Tret of warm extreme index (SU) decreased .On the basis of a systematic analysis of observed changes in extreme indices, a significant proportion of Iran was increasingly affected by a significant change in climate extremes in the period 1951-2003.

These are clear signs of changes which are very robust, however large areas are still not represented, especially the east and southeast of Iran. Changes in the occurrence of extreme indices can often have a far greater detrimental impact on ecosystems than a change in average climate conditions. Determining the precise contribution of climate variation to the frequency of extreme events is not, however an easy matter. Climate change does alter the frequency and severity of extreme events in various parts of the world. This study focuses on Iran as a complex climatological region. Additional research will undoubtedly provide accurate scenarios for the future.

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