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ENSO FORCING ON CLIMATE CHANGE IN IRAN: PRECIPITATION ANALYSIS*

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Abstract– An investigation was conducted to detect the change-point years in the Southern Oscillation Index (SOI) and precipitation time series in Iran for the period 1951-1999 (49 years). Due to the unavailability of data, the record length of the precipitation time series was not consistent for all stations, varying from 34 to 49 years. The Pettitt-Mann-Whitney and Mann-Whitney-Wilcoxon tests were applied to determine the significance of the detected changes. The difference in SOI and precipitation amounts for the period before and after the change years was investigated. The coincidence of change-point years in the SOI time series and precipitation data was explored to evaluate the possible forcing effects of the El Niño-Southern Oscillation (ENSO) phenomenon on the suppression or enhancement of Iran's hydrological cycle. The results indicated that the mid 1970s are the most probable change-point years in the time series of Southern Oscillation Index (SOI) data. The frequency and intensity of El Niño events have increased since then. Consistent with this finding, precipitation data from both south-western and northern parts of Iran have also shown significant change years in or around the mid 1970s. Compared to the period before 1975, annual precipitation over most of the studied regions has increased. This increase was found to be more considerable in southern rather than northern districts. Seasonal precipitation amounts in southern regions have generally increased during autumn and winter and decreased in spring. On the other hand, for northern regions, precipitation has increased during summer and autumn and decreased throughout winter and spring. The most enhanced portions of the hydrological cycle in the southern and northern regions were centred on March and May, respectively.

Keywords– El Nino, dry zones, wet zones, change-point, Mann-Whitney, SOI

1. INTRODUCTION

Iran has arid or semiarid climates mostly characterized by low rainfall and high potential evapotranspiration. The annual precipitation varies from about 1800 mm over the western Caspian Sea coast and western highlands to less than 50 mm over the uninhabitable eastern deserts (Fig. 1). The average annual precipitation over the country was estimated to be around 250 mm, occurring mostly from October to March. Annual precipitation is lower in the eastern half of Iran compared with the western half. In northern Iran, the Caspian Sea shores have an annual precipitation of about 500 mm in the east to 1800 mm in the west. In contrast to other parts of the country, the amount of spring and summer rainfalls are considerable in this region.

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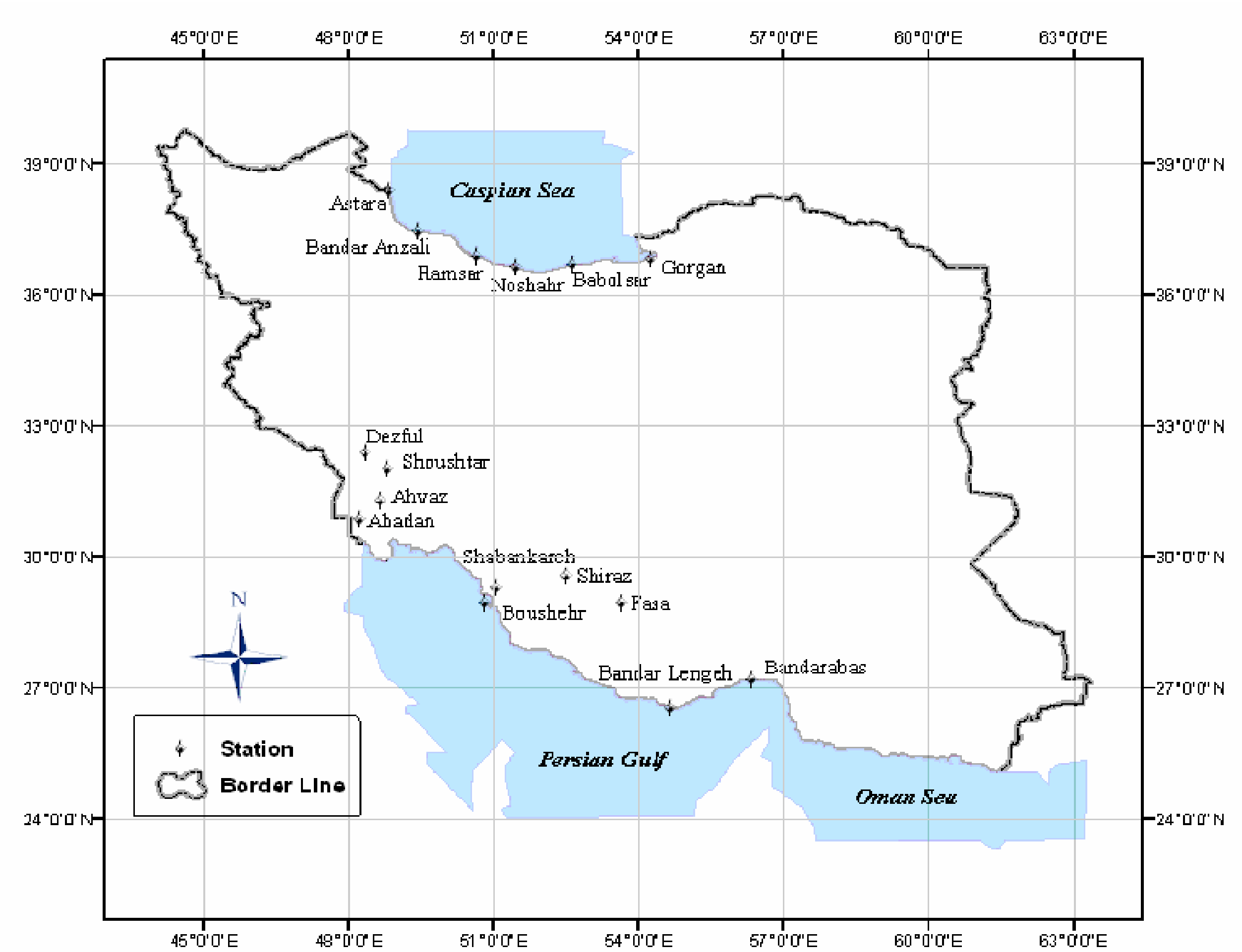

Fig. 1. Geographical location of the precipitation stations in southwestern and northern parts of Iran

Temperature variations are commonly used to detect and quantify possible changes in climate. Another means is to analyse trends, and variability in precipitation data. Some investigators have reported that there is an enhanced hydrologic cycle over the last two decades, especially for some parts of the Northern Hemisphere [1-5]. Although much emphasis has recently been placed to quantify climate change over different parts of the globe [1, 3, 6], the authors are unaware of any comprehensive studies dealing with the detection of climate change in Iran.

Bell *et al.* [7] have investigated the effects of climate change on the timing and length of the growing season and the frequency and intensity of extreme temperatures and precipitation. They have concluded that, if atmospheric carbon dioxide concentration is doubled, daily minimum and maximum temperatures in California would significantly be increased. A prolonged heat wave and protracted length of the growing season were considered as the consequences of such an increase. In contrast to temperature, the changes in total and extreme precipitation were not distributed evenly and found to be associated with the geographic location.

Nazemosadat and Cordery [8, 9], Nazemosadat [10, 11], and Nazemosadat and Ghasemi [12] have shown that the El Niño-Southern Oscillation (ENSO) phenomenon has a significant effect on winter and particularly autumn precipitation in Iran. These investigations suggest that, due to the intense warm (or El Niño) and cold (or La Niña) phases of ENSO, the intensity and predictability of dry and wet conditions in Iran are substantially altered. Furthermore, evidence indicates that the frequency and duration of ENSO are affected by climate change caused by an increasing CO_2 concentration in the atmosphere [13]. Past and future changes in precipitation and available water resources in Iran could, therefore, be associated with the trend in the Southern Oscillation Index (SOI) data, one of the most profound indicators of ENSO phenomenon.

The objective of this paper is to investigate and compare measures of climate change in the north (wet zone) and southwest (dry zone) of Iran based on the available precipitation data. Our analysis examines the possibility of the existence of a change-point year in these data, which identifies the year separating different precipitation patterns. Although this examination does not measure the possible trend in time series, it can prove the existence of various signs of trend in the data. The existence of a change-point year in the SOI data and its approximate coincidence with the change-point years in the precipitation data was also explored. The average values of SOI and precipitation data for the period before and after the derived change-point year were compared to justify the causes of climate change. The frequency of extreme precipitation events was also investigated for the pre and post period of the change-point years.

2. DATA AND STATISTICAL METHODOLOGY

The monthly precipitation data from 16 synoptic stations spread over two distinct regions, the south-western and northern parts of Iran, were analysed for the period 1951-1999. Figure 1 shows the geographical location of the stations, while Table 1 outlines the amounts of annual precipitation, as well as its seasonal distribution. As indicated in this table, 14 stations have 40 years or more of precipitation records. Annual, half-yearly and quarterly time series of these records were provided on the basis of the water budget calendar in Iran, which mostly started from late September of each year. On the basis of this calendar, autumn (Q.1), winter (Q.2), spring (Q.3), summer (Q.4), first half yearly (HY.1) and second half yearly (HY.2) were considered as October to December, January to March, April to June, July to September, October to March and April to September, respectively. The Troup [14] SOI data extracted from the web site of the Australian Bureau of Meteorology (www.bom.gov.au) was used as the ENSO indicator.

Table 1. Geographical position, record length, annual precipitation (mm) and its seasonal distribution (%) for the selected stations

Row	Station name	Long	Lat.	Length (year)*	An. mm	% Aut. (Qu.1)	% Win. (Qu.2)	% Spr. (Qu.3)	% Sum. (Qu.4)
1_{s**}	Abadan	48:1	30:2	49	152	38	50	12	0
2_s	Ahwaz	48:4	31:2	43	221	41	49	10	0
3_n	Astara	48:5	38:2	40	1197	41	22	14	23
4_n	Babolsar	52:4	36:4	41	885	46	26	9	19
5_s	Bandar Abbas	56:2	27:1	43	186	22	68	8	2
6_n	Bandar Anzali	49:3	37:3	49	1780	48	24	8	20
7_s	Bandar Lengeh	54:5	36:3	34	150	22	65	6	7
8_s	Boushehr	50:5	28:6	49	260	47	48	5	0
9_s	Dezful	48:2	32:2	41	390	34	51	10	5
10_s	Fasa	53:4	28:6	35	303	31	61	6	2
11_n	Gorgan	54:2	36:5	40	581	30	31	20	19
12_n	Noushahr	51:3	36:3	40	1337	46	21	11	22
13_n	Ramsar	50:4	36:5	45	1220	45	19	12	24
14_s	Shabankareh	51:6	29:2	41	238	38	56	6	0
15_s	Shiraz	52:3	29:3	49	346	31	58	11	0
16_s	Shoushtar	48:8	32:1	49	300	38	51	11	0

* all the records ended by 1999.

** The subscripts 's' and 'n' refer that the station is located either in southern or northern districts

The Pettitt-Mann-Whitney and Mann-Whitney-Wilcoxon statistics are frequently used for determining the year of change in time series [15, 16, 3]. Kiely [3] applied these tests for investigating climate change in Ireland as signified by the change in streamflow and precipitation data. The purpose of these statistics, which were adopted in the present study, is to determine in which year (or years) a significant change has occurred in a single time series.

The nonparametric Mann-Whitney and cumulative sum (Cumsum) tests [15] were used to identify the change-point year or years in the considered time series (annual, half-yearly, quarterly and monthly). The characteristics of these tests were described by Kiely [3] in some detail. For convenience, a brief description is presented below.

In Pettitt-Mann-Whitney test, every time series with length T, given by ($X, X, \ldots, X_T$), is considered as two samples represented by $X, X, \ldots, X_t$ and $X_{t+1}, X_{t+2}, \ldots, X_T$. The indices $V(t)$ and $U(t)$ were then calculated from

$$V_{t,T} = \sum_{j=1}^{T} \operatorname{sgn}(X_t - X_j) \quad (1)$$

$$U_{t,T} = U_{t-1,T} + V_{t,T} \quad \text{for } t = 2, T \quad (2)$$

and

$$U_{1,T} = V_{1,T} \quad (3)$$

where

$$\operatorname{sgn}(x) = \begin{cases} 1, x > 0 \\ 0, x = 0 \\ -1, x < 0 \end{cases} \quad (4)$$

The approximate significance probability $P(t)$ for a change-point is

$$P(t) = 1 - \exp\left(-6U_{t,T}^2 / T^3 + T^2\right) \quad (5)$$

The most significant change-point is found where the value $|U_{t,T}|$ or $P(t)$ is a maximum. In addition to the computation of $P(t)$, the cumulative sum (Cumsum) technique was also applied to detect changes in the sequence of observations ordered in time. The computed Cumsum for the time series confirms the change-point years detected by the Pettitt-Mann-Whitney test. The Cumsum is computed as follows:

$$S_j = \sum_{j=1}^{j} (X_j - k) \quad (6)$$

where k is the average value of the time series. The possible change has occurred when S_i is a maximum. We note that the range of the $U_{t,T}$ is approximately ten times that of the Cumsum of the x_t [15]. The magnitude of $|S_j|$ is therefore an auxiliary examination to investigate the significance of the observed change in the time series. As much as the maximum value of $|S_j|$ is greater, the no-change hypothesis is rejected at a higher significance level.

For all the considered time series (annual, half-yearly, quarterly and monthly), the magnitudes of $P(t)$ and S_i were computed for all 16 sites (altogether 304 time series). The year with the most significant probability (the coincidence of the highest values of $P(t)$ and max S_i) was then distinguished for every time series. The Mann-Whitney-Wilcoxon test was then used to explore if the identified $P(t)$ and S_i values are significant (α = 5%). The change-point year with the highest probability was then determined for all stations.

The relative frequency of severe dry, as well as very wet conditions for the period before and after change-point year was compared for each month. To accomplish this, the 15^{th} and 85^{th} percentile levels of each monthly time series were determined and selected as the thresholds for the dry and wet conditions, respectively. The time series were then divided into two parts (separated by change-point years) and the frequency of the events whose magnitudes were either lower than the 15th percentile or higher than the 85th percentile levels (or the frequency of the dry and wet events, respectively) were then determined for each part. For each section of the time series, the ratio of the number of severe dry or very wet conditions to the total number of observed records on that section was then computed. These ratios (or relative frequencies) were used as the criteria for quantifying the effects of climate change on the occurrence of severe dry or very wet conditions. For investigating if the frequency of milder wet or dry conditions is also consistent with the frequency of the extreme events, the computation of the relative frequency was recurred when the 30^{th} and 70^{th} percentiles are used as the thresholds for dry and wet conditions. Those results, confirmed by both percentile levels, are presented here.

3. RESULTS AND DISCUSSION

a) Change-point years in SOI data

Since the extreme phases of ENSO (El Niño and La Niña) induce a meaningful impact on the variability of seasonal precipitation in Iran [8-12,17], a trend in the precipitation time series could, therefore, partially be attributed to the change in SOI data. To examine the possible role of ENSO on climate change in Iran, the Mann-Whitney and cumulative sum tests were applied to detect the most probable change-point years in the SOI data stratified into various timescales. As a subsequent step, we assess the possible consequences of these changes on the precipitation over the dry (southern) and wet (northern) zones of Iran.

If the change-point years in precipitation and SOI data were mostly coincident and the signs of the trend for the period before and after these years was consistent in both time series, ENSO could be considered as the external mechanism for climate change in Iran.

As indicated in Table 2, 1975-76 are the most probable change-point years in the SOI time series stratified into annual, half-yearly, quarterly and even monthly timescales. The average values of the stratified SOI series show signs of a negative trend after 1975 (Figure 2). Therefore, since the mid-1970s, the frequency and intensity of El Niño and La Niña events have substantially increased and decreased, respectively. It is worthwhile to note that the NAO time series also exhibits a significant change-point in the mid-1970s [3]. Although the linkage between seasonal precipitation in Iran and the NAO data is generally weaker than corresponding associations with SOI [18], the proximity of the change-points of these two series suggests some meaningful variations in global climate since the 1970s.

b) Change-point years in precipitation data

Figure 2 shows the annual precipitation series, their 10-year moving average, linear trend and average line for Abadan as an example. The variation in moving average suggests the existence of three change-point years in this time series that are centred on 1961-62, 1975-76 and 1985-86. However, the adopted statistical tests suggest that, the most probable change-point year in the annual and first half-yearly (October to March) records of the observed data are 1972-73 (Fig. 3). Table 3 summarizes the change-point years and corresponding $P(t)$ values for those time series that exhibit a significant change. The content of the last column (column 6) of Table 3 shows the years that exhibit the highest frequency in (column 4), as well as a high value for $P(t)$ in (column 5). It is worthwhile to note that, for Boushehr and Shiraz, the exceptional rainfall recorded during autumn 1957 was clearly inconsistent with nearby stations and removed from the analysis. The overall information presented in this table suggests that the change-point years have mostly occurred during the 1970s.

Table 2. The results of Pettitt-Mann-Whitney test for SOI time series (1951-1999) as well as the mean values of SOI pre and post of 1975

Time series SOI	Change point year (Year/Years)	Significance probability (P(t))	Mean value of SOI	
			Pre-1975	Post-1975
An.	1975-76	0.983	21.79	-38.83
HY1* (Oct. - Mar.)	1976-77	0.892	9.05	-18.44
HY2(Apr. – Sep.)	1975	0.885	12.74	-20.39
Qu.1(Oct. – Dec.)	1976	0.912	5.07	-7.76
Qu.2(Jan. – Mar.)	1976	0.856	3.98	-10.68
Qu.3(Apr. – Jun.)	1975	0.88	5.59	-11.73
Oct.	1976	0.936	1.69	-3.05
Mar.	1976	0.991	2.55	-6.31
Apr.	1976	0.961	2.03	-6.37
Aug.	1975	0.928	3.25	-3.91

* HY =half yearly

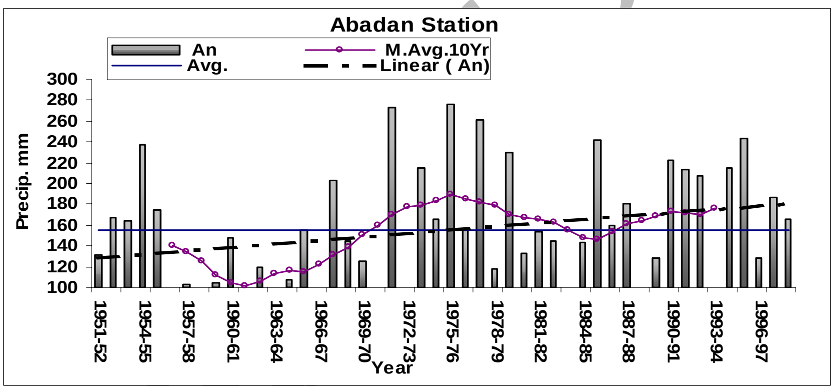

Fig. 2. Annual precipitation and its 10 year moving average, trend line and long-term average line in Abadan

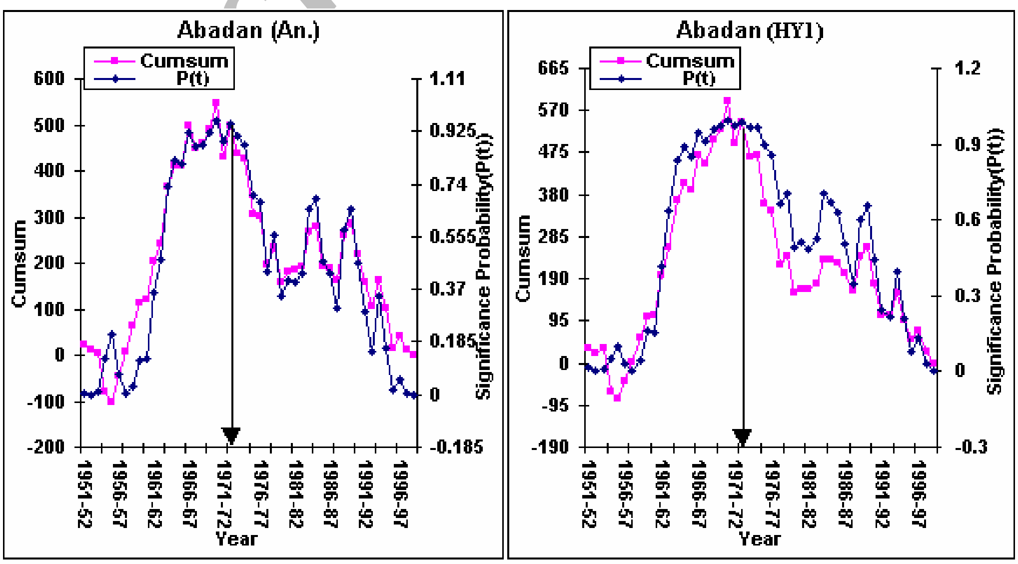

Fig. 3. The significance probability of change point and cumulative sum for annual (Left) and first half yearly (Right) rainfall time series in Abadan

After denoting the change point year for each time series, the precipitation average was computed and compared for the periods before that year. It is worthwhile to note that, if a precipitation time series was separated into two parts, the maximum difference in the averages of these parts was obtained if the change-point year bisected the time series. However, for convenience, instead of the denoted change point years, the year 1975 was considered as the change point year of all time series through the difference in average values are not maximized. The percentage of precipitation change in the annual, half-yearly and seasonal time series for the later period relative to the earlier period is presented in Table 4. According to this table, annual precipitation in south-western Iran has considerably increased post-1975, mainly due to the increase in autumn (Qu1) and winter (Qu2) precipitation. On the other hand, these areas have mostly experienced a decrease in spring precipitation (Qu3) ranging from about 10% to 50%. This means that, for post 1975, there is a tendency toward excess precipitation during cold seasons and toward more dryness during warm seasons.

Table 3. The results of the Pettitt-Mann-Whitney test for the precipitation time series in the north and southwest of Iran

Row	Station	Time series with change	Change years (respectively)	(p(t)) (respectively)	Probable change year
1_{s*}	Abadan	An., HY.1 HY.2, Qu1, Qu.2 Qu.3,.	72-73, 72-73 72, 70, 73 72,	0.95, 0.99 0.86, 0.90, 0.99 0.86,	1973
2_s	Ahwaz	An., HY.1, HY.2 Qu.1, Qu.2, Qu3.	72-73, 72-73, 75 73-79- 75	0.99, 0.99 0.94, 0.97	1973
3_n	Astara	An., HY.1	84-85, 74-75	0.896, 0.914	1975
4_n	Babolsar	An., HY.1 HY.2, Qu.2	70-71, 70-71 86, 79	0.95, 0.92 0.87, 0.72	1971
5_s	Bandarabbas	An., HY.1, Qu1, Qu.2.	72-73, 72-73, 73, 73	0.97, 0.93, 0.81, 0.86	1973
6_n	Bandaranzali	An., HY.1 HY.2, Qu3, Qu4	63-64, 88-89 69, 69, 62	0.93, 0.85 0.97, 94, 0.92	1969
7_s	Bandarlengeh	HY.2, Qu.1	77, 78	0.94, 0.59	1977
8_s	Boushehr	An, HY1, Qu.1.	70-71, 70-71, 70	0.76, 0.81, 0.81	1970
9_s	Dezful	An., HY.1.	90-91, 70-71	0.84, 0.94	1975
10_s	Fasa	HY.2, Qu3	77, 77	0.88, 0.87	1977
11_n	Gorgan	An., HY.1 Qu.1, Qu.2 Qu.3	80-81, 78-79 80, 79 84	0.99, 0.99 0.93, 0.99 0.91	1979
12_n	Noushahr	Qu.3.	78	0.93	1978
13_n	Ramsar	Qu.2.	72	0.87,	1972
14_s	Shabankareh	An., HY.1 Qu.2,	70-71, 70-71 71	0.98, 0.98 0.98	1971
15_s	Shiraz	An., HY.1 Qu.1, Qu.2	73-74, 74-75, 71, 77	0.81, 0.91, 0.84, 0.85, 0.76	1974
16_s	Shoushtar	HY.1, HY.2, Qu.3	70-71, 76, 76	0.87, 0.8,0.90	1976

* The lowercases “s” and “n” indicate if the station is either situated over southern or northern regions, respectively

For the northern districts, with the exception of Bandaranzali and Gorgan (situated on the western and eastern coasts of the Caspian Sea, respectively), annual rainfall has increased since 1975, mostly due to the increase during autumn and summer. A persistent decrease in the annual rainfall at these two stations is a notable feature of the present study. The increase in the summer rainfall in Noushahr, Babolsar and Gorgan situated over the central and eastern parts of the Caspian Sea is also remarkable. As indicated in Table 4, compared to western areas, the eastern shore of the Caspian Sea is more susceptible to excess precipitation and possibly flood events during summer. Some recent devastating flood events in Gorgan and nearby regions on the eastern coast of the Sea could, therefore, be attributed to climate change. Furthermore,[17,12] have recently shown that, in addition to ENSO, precipitation variability over the Caspian Sea coasts is significantly influenced by the surface temperature of the sea, and the intensity of the Siberian high.

The results suggest that there are some differences between the pattern of climate change in northern and southern parts of Iran. Compared to southern areas, rainfall time series in northern districts exhibit smaller increases and a less marked change after 1975. Moreover, although both regions have, respectively, experienced a decrease and increase in spring and autumn rainfall since the mid-1970s, the change in winter rainfall follows different patterns for southern and northern areas. In spite of the fact that southern districts have mostly experienced a positive trend in winter rainfall for recent periods, the trend was generally negative for the Caspian Sea coastal regions. This suggests that, for southern regions, the occurrence probability of excess winter precipitation was increasing over the past two decades. On the other hand, for these decades, the frequency of wintertime dry events was increased in northern districts. While summer precipitation (Qu.4) is near zero for southern regions, this precipitation has generally increased for northern areas.

The analyses of monthly rainfall have revealed that, for northern districts, the prominent increase in average precipitation was evident in October, November, February and almost September. On the other hand, since 1975, March precipitation of these districts has consistently decreased. In contrast with northern areas, average precipitation was mostly enhanced for March and suppressed in January and December for the majority of south-western stations. For these stations, the decreasing inclination in the rainfall during April and May will lead to accentuated dry periods, a situation that is cause for concern.

Table 4. The percentage of the increase (I) or decrease (D) in precipitation amount for the period after 1975 with respect to the period before this year

Station	An.	HY.1	HY.2	Qu.1	Qu.2	Qu.3	Qu.4
Abadan	I, 31%	I, 40%	D, 14%	I, 31%	I, 46.%	D, 14%	-
Ahwaz	I, 25%	I, 36%	D, 43%	I, 41%	I, 3%	D, 45%	-
Astara	I, 16%	I, 23%	I, 5%	I, 30%	I, 13%	I, 10%	I, 3%
Babolsar	I, 18%	I, 20%	I, 15%	I, 19%	I, 20%	I, 3%	I, 20%
Bandar Abbas	I, 55%	I, 55%	I, 79%	I, 70%	I, 50%	I, 75%	-
Bandar Anzali	D, 2%	I, 4%	D, 14%	I, 8%	D, 3.5%	D, 23%	D, 10%
Bandar Lengeh	I, 51%	I, 57%	D, 47%	I, 98%	I, 54.%	I, 14%	-
Boushehr	I, 2%	I, 6%	D, 54%	D, 14%	I, 29%	D, 59%	-
Dezful	I, 20%	I, 30%	D, 38%	I, 31%	I, 29%	D, 8%	-
Fasa	I, 26%	I, 37%	D, 45%	I, 55%	I, 3%	D, 50.%	-
Gorgan	D, 1%	D, 3%	D, 5%	D, 17%	D, 10%	D, 10%	I, 2%
Noushahr	I, 7%	I, 5%	I, 10%	I, 13%	D, 8%	D, 11%	I, 25%
Ramsar	I, 5%	I, 10%	D, 4%	I, 20%	D, 8%	D, 9%	D, 2%
Shabankareh	I, 55%	I, 61%	D, 15%	I, 43%	I, 7%	D, 10%	-
Shiraz	I, 10%	I, 16%	D, 29%	D, 1%	I, 25%	D, 9%	-
Shoushtar	I, 5%	I, 14%	D, 49%	I, 3%	I, 25%	D, 10%	-

c) Statistics of severe dry or very wet conditions

This section is devoted to examining the relative frequency of severe dry, as well as very wet conditions (the precipitation below 15^{th} or above 85^{th} percentiles, respectively) for the periods before and after 1975. As indicated in Table 5, since 1975, the relative frequency of severe dry events in Abadan (Station 1) has considerably reduced from November to March indicating a shift toward drought-avoidance during these months. Conversely, this frequency shows about a 4.1% increase in April suggesting the increased likelihood of dryness during this month post-1975. Furthermore, the relative frequency of very wet conditions has recently increased for November, December, March and February in particular. It is noteworthy that the abrupt increase in the frequency of wet circumstances during February and March was not restricted to Abadan, but is a general climatic feature of the south-western regions (Table 5). Consistent with this increase, the frequency of the severe dry events was also reduced for these two months. The given results suggest a tendency for increasing the frequency of winter floods and decreasing severe dryness for south-western regions.

Table 5. The percentages of increase or decrease in the relative frequency of severe dry and very wet conditions for the period after 1975 (compare to the period before this year). The Bold & Italicized numbers signify if the occurred decrease or increase is in favor of flooding or dryness, respectively

		Months of year											
St. [1]		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1_s	Dry	-	-12	-4	-12*	-4*	-12*	4*	-**	-	-	-	-
	Wet	-	4*	4*	-4	12*	4*	-4*	-	-	-	-	-
2_s	Dry	-	-4*	6*	-14*	15*	-23*	5*	-	-	-	-	-
	Wet	-	5*	15*	-13	15*	15*	-13*	-	-	-	-	-
3_s	Dry	-1	-13*	-13*	-2*	-2*	2*	-2	-24*	2*	-20*	2*	9
	Wet	9*	9.*	-2	-24	21*	9*	-13	9*	2	-2	-2*	-2
4_n	Dry	-17*	4*	4*	-6*	-6*	15*	15*	-6*	2	-6*	4*	4
	Wet	15*	15*	-17*	25*	15*	-6*	-17*	15*	-6*	-6*	15*	15
5_n	Dry	-	17*	-23*	-4	-14*	-14*	-3*	-	-	-	-	-
	Wet	-	-23*	15*	-4	15*	25*	5*	-	-	-	-	-
6_s	Dry	-12*	4	-4*	4	-4*	4*	21*	-4*	12*	-4	4*	4
	Wet	12*	-12*	-4	-4*	4	-29*	-12*	-4	-4*	4	-4*	-12*
7_n	Dry	-	-5*	-12*	5*	-6	-14*	39*	-	-	-	-	-
	Wet	-	17*	17*	1	17*	17*	1*	-	-	-	-	-
8_s	Dry	-	-8*	-4*	-17*	4	-21*	-4*	-	-	-	-	-
	Wet	-	-4*	-12*	-12*	12*	12*	-1	-	-	-	-	-
9_s	Dry	-	8	-6*	-17*	14	-37*	8	-	-	-	-	-
	Wet	-	4	14*	-17*	15*	15*	-27*	-	-	-	-	-
10_s	Dry	-	-12.*	0	17*	-17*	-17*	4*	-	-	-	-	-
	Wet	-	0	17*	-17*	17*	0	-17*	-	-	-	-	-
11_s	Dry	-1	-1	3*	21*	-1	21*	10*	-1	21*	-1	10*	-8*
	Wet	-22*	-12*	-12*	-1*	10*	-22*	3	10*	-12*	-1*	10*	10
12_n	Dry	-24*	-2*	9*	-2*	21	21*	9*	-2	21*	-2	21*	-13*
	Wet	9*	9*	-24*	-13*	-2	-2*	-21*	9*	-2*	-2	9*	21*
13_n	Dry	-12*	7	7*	-2*	7*	7*	7*	-2*	25*	-2*	25*	-12
	Wet	7*	-2*	-2*	-21*	7	-12*	-2*	16*	-2*	-12*	7	7*
14_n	Dry	-	-10*	-6*	-6*	4	-33*	4*	-	-	-	-	-
	Wet	-	4	14*	4*	25*	14*	4	-	-	-	-	-
15_s	Dry	-	-4*	-12*	4	8.3	-12*	4	-	-	-	-	-
	Wet	-	4	-4*	-12	29*	4*	-12*	-	-	-	-	-
16_s	Dry	-	-4	4*	-21*	12	-12*	4*	-	-	-	-	-
	Wet	-	-4	-12	4*	-4	12*	-21*	-	-	-	-	-

1= The stations are in the same order as in Table 1. The lowercases "s" and "n" denotes if the station is situated over southern or northern regions.
* Also accepted for lower than 30^{th} percentile and higher than 70^{th} percentile
** No considerable rainfall for this month

In contrast to winter, a sharp decrease in the relative frequency of wet conditions and increase in the frequency of dry episodes during April and May prompted a significant shift toward further dryness of southern regions during the warm months of the year. Our conclusion is that, for southern areas, soil and water conservation policies need to be implemented for efficient utilization of available water and for storing excess winter rainfall to compensate the increasingly long dry spring and summer seasons.

Compared to southern regions, less consistency of the relative frequencies of dry and wet conditions were found between the considered stations in northern districts. During the last two decades the frequency of very wet conditions has generally increased during October, November, February, May and September, while the frequency of severe dry events has mostly increased during December, April, June and August.

There are some discrepancies between the occurrence dates of wet and dry events in northern and south-western regions. For instance, as the frequency of wet and dry epochs in the south was increasing and decreasing during March, for most of the northern stations, the observed trends in this month were opposite to that of the south. Similarly, a tendency towards an increase/decrease in the frequency of wet/dry events in northern regions in May is in the opposite direction to that for southern areas.

4. CONCLUTIONS

The study has demonstrated that for both precipitation and SOI time series, the change-point years occur near the mid-1970s. While the annual precipitation has usually increased for the period after 1975, the magnitude of the SOI was mostly negative for this period. This implicates that the increase in the frequency, strength and the duration of El Niño/La Niña episodes was generally associated with above/below normal precipitation over northern and particularly southern regions of Iran. The El Niño-Southern Oscillation phenomenon was, therefore, introduced as a factor forcing climate change in Iran. The observed increased rate in the rainfall of northern districts was not as large as that for the south.

For northern/south-western regions, the increase in annual precipitation was found to reflect the increase in summer and autumn/winter and autumn precipitation. While average winter rainfall over southern regions has increased during the last two decades, it has decreased for northern districts. Spring rainfall, however, exhibits a negative tendency over both regions, a finding that foreshadows intensified socio-economic dilemmas associated with water shortages during the summer, particularly for southern regions.

For southern and northern districts, the relative frequency of very wet conditions has commonly increased during March and May, respectively. Consistent with the increase in wet conditions, the relative frequencies of severe dry conditions has decreased for northern and southern regions in March and May, respectively. Therefore, the most enhanced hydrological cycle is related to March in the south and to May in the north. It has been found that while for southern regions the frequency of very wet/severe dry events is increasing/decreasing during March, it is decreasing/increasing in the north.

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