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Winter Drought in Iran: Associations with ENSO

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Introduction

The Islamic Republic of Iran (Figure 1) has an area of 1,648,000 km^2 and a population of 65 million people (1995 estimate). The country has arid and semiarid climates and the occurrence of rainfall is unreliable, with a coefficient of variation as high as 70%. The average annual precipitation over the country is around 250 mm. Two mountain ridges, the Alborz and Zagros (Figure 1), which run east and southeast from the northwest corner of the country, play an influential role in determining the amount and spatial distribution of rainfall. The peaks of Alborz and Zagros are about 5,700 m and 4,000 m, respectively.

Rainfall generally occurs from October to March (winter), with extreme events during January and February. Annual rainfall over the northern sides of the Alborz range may reach 1,800 mm, but for the central and eastern deserts, the yearly total is around 50 mm. Droughts and floods are common, and the severity and hardships of these natural disasters frequently hit both rural and urban societies. Drought limits dryland farming and affects the productivity of irrigated lands. Moreover, due to massive overgrazing, large-scale soil erosion occurs during dry spells. Atmospheric and climatic incidents (i.e., floods, droughts, and lightning) account for about 97% of all natural disaster costs. Concern about water resources is currently realized as one of the most important issues for most of the Iranian scientific and management communities. Most parts of the Islamic Republic of Iran recently experienced an exceptional drought that lasted more than 2 years (1998–2000). In some areas, drought has also extended into winter 2001. The 1998–2000 drought inflicted $3.5 billion in damages, killing 800,000 head of livestock and drying up major reservoirs and internal lakes (Pagano et al., 2001).

Nazemosadat and Cordery (2000a) and Nazemosadat (1999) have recently revealed that the autumn rainfall in Iran is negatively correlated with the Southern Oscillation Index (SOI). The relationships were found to be strong and consistent over the southern foothills of the Alborz Mountains, northwestern districts, and central areas. Since winter rainfall contributes a major portion of Iranian water resources, the shortage of rainfall during this season is the most important cause of drought in Iran. Nazemosadat and Cordery (2000b) have therefore focused on the impact of ENSO on winter precipitation in Iran. The present study outlines some key results of the aforementioned studies.

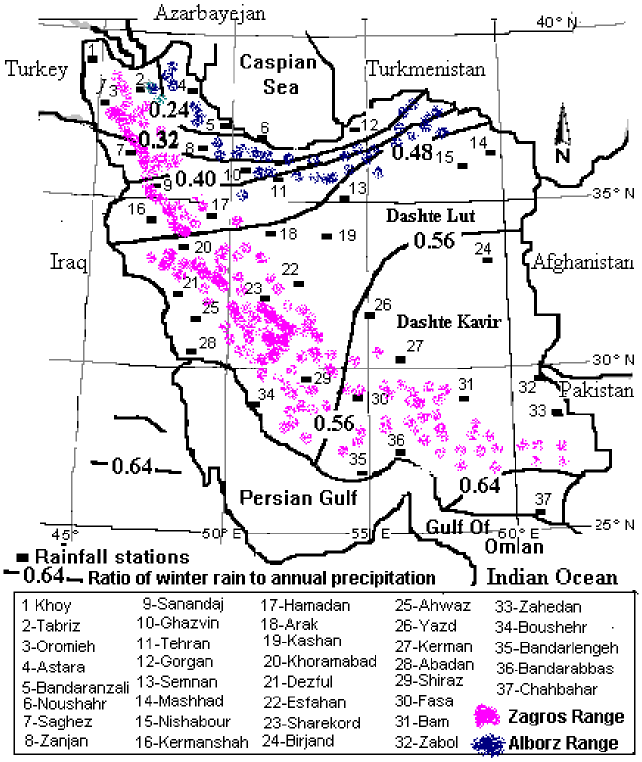

Figure 1. Rainfall stations whose data were analyzed in this study. Contour lines depict the ratio of winter rainfall to annual precipitation.

Data and Methods

The basic data used in this study were monthly rainfalls for 36 stations, obtained from the yearly Weather Books published by the Iranian Meteorological Organization (IMO) for the period 1951–95. Figure 1 shows the location of these stations. It also shows the ratio of winter rainfall to annual precipitation. Average annual rainfalls vary from 62 mm in Yazd and Zabol to 1779 mm in Bandaranzali. As indicated in Figure 1, winter rainfall contributes 25%–70% of the total annual rainfall in different parts of the country.

The SOI data (one of the ENSO indicators) were supplied by the Australian Bureau of Meteorology. The low and high phases of ENSO were identified from a list provided by Trenberth (1997). He defined El Niño and La Niña events as those where sea surface temperatures in the so-called Niño 3.4 region differed from their mean by more than ±0.4°C. The study here used these lists to detect the warm and cold phases of the SO phenomenon. In addition, for episodes in which winter SOI was greater than +5 and less than -5, the magnitudes of average rainfalls were also examined.

The time series of winter rainfalls was obtained by averaging the 3-month values of precipitation. Best results were obtained by defining winter from January to March. The same averaging procedure was performed to provide the seasonal time series of SOI data.

Nazemosadat and Cordery (1997 and 2000) and Cordery and Opoku-Ankomah (1994) have used a sequential correlation analysis (SCA) to examine the strength and temporal stability of the relationship between rainfall and climatic indices. The SCA was also used to detect trends in the correlation between variables, as well as any instability in the rainfall–SOI relationships.

The data lengths employed for the correlation analysis varied from a minimum 15-year window width to the total period of available data for every station. The selection of the various window widths allows the assessment of the effect of record length on the strength and stability of the correlations. For each selected window width, correlation coefficients were calculated for continuous data periods. For example, for 25-year window widths, correlations between Tehran rainfall and SOI were calculated for windows of 1951–75, 1952–76, ..., and 1971–95, a total of 21 windows. The correlation coefficients were computed for various window widths, but only the results for 15- and 25-year window widths are shown here. Results for other window widths were similar.

Results

Winter Drought and Extreme ENSO Phases

The linkage between SOI and rainfall during extreme phases of the SO events was also examined. Figure 2 shows the ratio of the average winter rainfall during El Niño (R_{El}) periods to the corresponding values of rainfall during La Niña (R_{La}) episodes. The ratio of (R_{El})/(R_{La}) is less than unity for most parts of Iran and greater than unity in a few stations such as Bam, Chahbahar, Oromieh, and Sanandaj. Cold (warm) events therefore generally coincided with drought (excess rainfall) conditions in these few stations. However, as indicated in Figure 2, for the main parts of Iran, El Niño episodes seem to coincide with shortage of rainfall and hydrological drought. Moreover, for some stations, including Noushahr, Bandaranzali, Zanjan, Dezful, Zahedan, Shiraz, and Arak, the ratio is less than 0.8, which suggests that, during warm episodes, severe drought is highly probable for these regions. For a number of rainfall stations, such as Esfahan, Yazd, Tabriz, Nishabour, Saghez, Zabol, and Bandarabbas, the ratios are close to unity, which indicates that ENSO has little influence on rainfall variability.

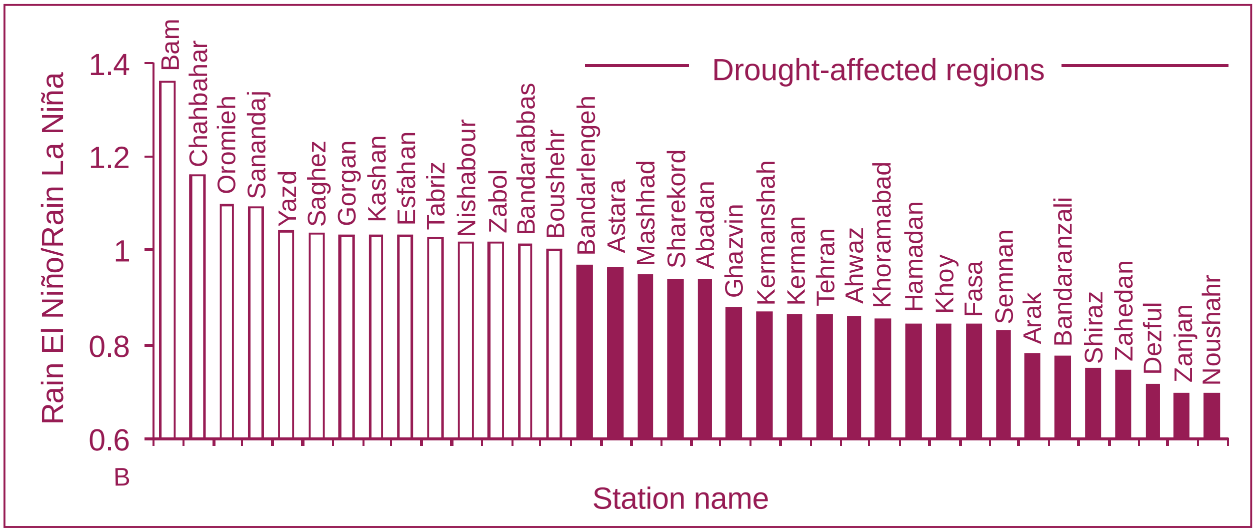

Figure 2. Ratio of winter rainfall during a cold phase of ENSO to the corresponding values during a warm phase.

Nazemosadat and Cordery (2000a) have already shown that for most of the country, rainfall in autumn is negatively correlated with SOI. By comparing the SOI–rainfall relationships during autumn and winter, it can be concluded that the influence of ENSO on Iranian rainfall is mostly reversed from autumn to winter. This reversal of the impact of the SO events on rainfall complicates the assessment of the overall effect of ENSO on annual precipitation. This reversal also complicates the prediction of rainfall during late autumn to early winter (December and January months).

The SOI–Rainfall Relationships: Decadal Aspects

The SCAs between SOI and winter rainfall for Noushahr, Bandaranzali, and Zahedan were significant (at 5% significance level) and positive. The first two stations are located on the Caspian Sea coastal strip and the others are located in the southeast. For the other stations, the correlation coefficients were found to be weak with a high temporal instability. The weak correlations were, however, positive for the majority of the stations. It is noteworthy that the correlations were generally found to be stronger and more persistent during autumn than in winter.

Figure 3 (a and b) shows the sequential correlation coefficients between SOI and winter rainfall in Bandaranzali, Zahedan, and Noushahr for 25- and 15-year window widths. Although the correlations for Zahedan, located in the eastern part of the country, are generally stronger and more persistent than for the other two stations, further research is needed to investigate why the relationships are weak for the neighboring stations of Zahedan (e.g., Bam, Birjand, and Zabol). It should be noted that during the decade 1960–70, the SOI–rainfall relationships are mostly weaker than those for the 1970–80 period. Figure 3b also suggests that the correlations are weakening when the periods after 1990 are included in the analysis. The study has concluded that the frequency of cold and warm events during these decades could justify temporal variations in SOI–rainfall relationships.

It is noteworthy that, in 1970s, the frequency of La Niña events (for winter) is more than for both the 1960s and the 1990–95 period. In the 1970s, the cold phase of ENSO occurred during 1971, 1972, 1974, and 1976. On the other hand, the warm episodes occurred only in 1970 and 1978. The total durations of cold and warm episodes during this decade are 52 and 34 months, respectively. In contrast to the 1970s, Trenberth (1997) does not report a cold winter event for the periods 1960–69 and 1990–95, in which the SOI–rainfall relationships are weak. The total length of La Niña events for 1960–69 is 9 months (May 1964 to January 1965). By contrast, total duration of El Niño episodes in the 1960s is about 40 months. The decades of the 1960s and 1970s could therefore be categorized as warm and cold periods, respectively. The correlation analyses for these periods suggest that the SOI–rainfall relationships are stronger during cold events than during warm episodes.

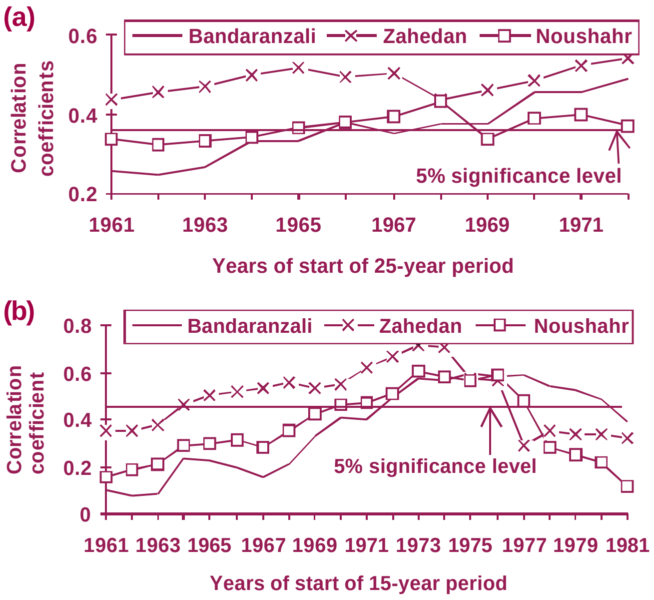

Figure 3. Sequential correlation coefficients between SOI and rainfall for winter in Bandaranzali and Noushahr for (a) 25-year window width and (b) 15-year window width. Numbers on horizontal axis refer to the first year of the window interval.

Combined Indicators

The study also examined which of the SOI and Niño 3.4 SST criteria could better explain variability of winter rainfall in Iran. To categorize warm and cold epochs, those years in which winter SOI were less than (-5) and above (+5) were considered El Niño and La Niña periods, respectively. For the available data set (45 years), 10 events in which SOI was less than (-5) and Niño 3.4 was more than (+0.4°C) were detected. In 7 of these events, rainfall was below normal over most of the country. The results indicate that, during warm events, the measure of the influence of ENSO events on winter rainfall in Iran depends on both the pressure gradient across the Pacific Ocean and the magnitude of Niño 3.4 SSTs. In other words, if either the SST is not sufficiently above normal or the pressure gradient is not adequately large, ENSO does not account for a significant portion of variability in winter rainfall in Iran.

For the spells for which both criteria (SOI and Niño 3.4) indicated cold events, the response of winter rainfall to ENSO was also studied and compared. The results suggest that for about 60% of the events, rainfall over most parts of the country was above normal. However, rainfall in Bandaranzali and Noushahr was found to be above normal for about 90% of the cases in which winter SOI was more than (+5) and Niño 3.4 was less than (-0.4°C). Further research is recommended to evaluate the impact of intense ENSO on Iranian rainfall.

Acknowledgments

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