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Spatiotemporal trends and change point of precipitation in Iran

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ABSTRACT

The analyses of the spatial and temporal trends of precipitation are pertinent for the future development and sustainable management of water resources of a given region. Annual and seasonal precipitation data from 28 synoptic stations of Iran (1967–2006) were analyzed to determine the spatial and temporal trends and approximate year of the beginning of the significant trends by using the Mann–Kendall and Mann–Kendall rank statistic tests, respectively. The trend free pre-whitening (TFPW) method was applied to eliminate the influence of serial correlation on the Mann–Kendall test, and the magnitude of the precipitation trends was obtained from the Theil–Sen's slope estimator. Over the 40-year period, negative trend in annual precipitation occurred at 22 sites (79%), while just three sites had statistically significant ($\alpha = 0.05$) negative trend in precipitation. The magnitude of the significant negative trends of annual precipitation at the 95% confidence level varied from $(-)2.53 \pm 0.69$ mm/year at Tabriz station to $(-)3.43 \pm 0.81$ mm/year at Khoy station. The change points of the annual precipitation at Khoy, Oroomieh and Tabriz stations were 1982, 1994 and 1981, respectively. In the seasonal series, the negative trends in spring and winter precipitation were larger compared with those in the other seasonal series, so that, five significant negative trends were detected in the winter time series. A noticeable decrease in the winter precipitation series was observed mostly in northern Iran, as well as along the coasts of the Caspian Sea. In summer precipitation, two significant positive trends were found at Mashhad and Torbateheydarieh stations, whereas no significant positive or negative trends were detected by the trend tests in autumn precipitation.

1. Introduction

Continuously increasing concentration of atmospheric carbon dioxide resulting in global warming, due to the increased greenhouse effect, is likely to have significant effects on the hydrological cycle (IPCC, 2007). The historical surveillance of climatic variables is receiving more and more attention, as many scientists are attempting to confirm whether or not there is an obvious climate change signal subsequent to the greenhouse effect (Easterling et al., 2000). As a result of the climate change, the water cycle will be intensified, with more evaporation and more precipitation. Nevertheless, the precipitation amount will be unequally distributed around the globe and several parts may see significant reductions in precipitation, or major changes in the timing of wet and dry seasons. Precipitation is one of the most important variables in the global hydrological cycle, for meteorology and climate (Prigent, 2010). Understanding the spatial and temporal variability of precipitation is important not only to weather forecasters and climate scientists, but also to a large range of decision makers, including hydrologists, agriculturalists, and industrialists (Brunsell, 2010).

One of the most important requirements of research about climate change is to analyze and discover historical changes in the climatic system (IPCC, 1996). In the last years, several researchers studied variability and trends in precipitation throughout the world (Bocheva et al., 2009; Caloiero et al., 2011; de la Casa and Nasello, 2010; de Luis et al., 2000, 2010; del Rio et al., 2005; Huang et al., 2009; Krishnakumar et al., 2009; Li et al., 2011; Liu et al., 2008; Partal and Kahya, 2006; Qin et al., 2010; Subash et al., 2011; Ventura et al., 2002; Xu

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et al., 2010, 2011; Zhang et al., 2009). Gong and Wang (2000) and Qian and Zhu (2001) recognized significant negative precipitation trends for different regions of eastern China from 1954 to 1976 and then positive trends from 1977 to 1998. Yue and Hashino (2003a) assessed long-term trends in Japan's annual and monthly precipitation by the Mann–Kendall test. They reported that monthly precipitation declined considerably from September through January. In addition, near the southern islands of Japan both annual and monthly precipitation decreased significantly from September to February and in June and July.

Becker et al. (2003) detected the significant positive and negative trends on a monthly precipitation for the second half of the last century for different regions of China. They reported many positive trends in January, June, and July and many negative trends in February, September, and November. de Lima et al. (2010) investigated the trends of annual and monthly precipitation at 10 stations in mainland Portugal by using the Mann–Kendall and Sen's non-parametric methods for long time series. They found significant sequence of alternating negative and positive trends in annual and monthly precipitation, which were sometimes statistically significant. Liang et al. (2011) studied the temporal variation and spatial distribution of precipitation in Northeast China from 1961 to 2008. The results revealed different patterns of trends on both monthly and annual scales, moreover, the mean annual and summer precipitation rates decreased in a southeastern to northwestern trajectory throughout the 48-year period due both to the influence of the East Asian monsoon and to topography.

Iran is located in the mid-latitude belt of arid and semi-arid regions of the Earth. The climate of the country is mainly arid or semi-arid, except the northern coastal areas and parts of western Iran. Distribution of precipitation in the country is uneven. The average amount of precipitation over the country is 252 mm/year, which is less than one-third of the world average (Alizadeh and Keshavarz, 2005). About 30% of the precipitation is in the form of snow, and the rest is rain and other forms of precipitation (Mousavi, 2005). Precipitation in Iran has a high spatial and time variability. There are regions in the south of the Caspian Sea, which receive up to 2000 mm of annual precipitation, whereas portions of the central and eastern parts of the country get less than 50 mm. Furthermore, most of the precipitation in Iran falls during the winter and autumn seasons, due to the prevalence of humid westerly winds of Mediterranean origin. However, there are regions in the northwestern part of the country that are characterized by high precipitation also during spring (Raziei et al., 2009).

Raziei et al. (2005) investigated annual precipitation from 1965 to 2000 for climate variability and possible trend by the Mann–Kendall test in Iran. The results showed that there was no evidence of climate change in the study area. While many stations showed negative trends, these trends were not statistically significant at the 95% confidence level. In another study, some Iranian stations (e.g. Bandar-Anzali, Tabriz, Zahedan) showed a negative trend in precipitation while others (e.g. Mashhad, Shiraz) experienced positive trends (Rahimzadeh, 2006). Modarres and da Silva (2007) analyzed the time series of annual rainfall, number of rainy-days per year and monthly rainfall of 20 stations by the Mann–Kendall test to assess climate variability in the arid and semi-arid regions of Iran. Their results showed that there was no significant climate variability in the arid and semi-arid environments of Iran. Tabari et al. (2011f) analyzed the trends of the annual precipitation time series in the west, south and southwest of Iran for the period 1966–2005. Their results showed no visible precipitation trends for the period in the study area. Tabari and Hosseinzadeh Talaee (2011c) examined the temporal trends of precipitation at 41 stations in Iran for the period 1966–2005 using the Mann–Kendall test, the Sen's slope estimator and the linear regression. They used the effective sample size (ESS) method to eliminate the effect of the lag-1 serial correlation on the Mann–Kendall test. The results showed a significant negative trend in annual precipitation series at seven stations. In addition, the numbers of the significant trends in the winter series were higher than those in the other seasonal series.

In spite of that several efforts have been made to examine the precipitation trends in Iran during the last decades, no comprehensive research has been conducted to determine the approximate year of the beginning of the significant precipitation trends by the Mann–Kendall rank statistic test. Furthermore, most of the previous studies didn't consider the serial structure of the precipitation time series which can adversely impact the power of the trend tests. In this work based on the precipitation data of 28 Iranian stations, the spatial distribution of the temporal trends in the annual and seasonal precipitation time series for the period 1967–2006 was examined. The objective was to investigate the changes in precipitation during this period, and to outline the climate fluctuations in the study region. Analyzing the variation of precipitation may lead to a better understanding of climate variability in Iran.

2. Materials and methods

2.1. Data

Examination of climate changes needs long and high quality records of climatic variables. In the present study, the time series of annual and seasonal precipitation data from 28 synoptic stations in Iran (Fig. 1) for the period 1967–2006 were collected from the Islamic Republic of Iran Meteorological Organization (IRIMO). Selection of the stations was carried out by taking into account the stations used in our previous study (Tabari et al., 2011f). Spatial distributions of the 28 stations are shown in Fig. 1 and their characteristics and data availability are presented in Table 1.

2.2. The used methods for trend detection

In this research, trend detection was carried out by the Mann–Kendall test, and the Mann–Kendall rank statistic test was used for determining the approximate year of the beginning of the significant trends at the 95% confidence level and the Theil–Sen's estimator for the trend magnitudes. Brief explanations of these methods are as follows:

2.2.1. Mann–Kendall test

The Mann–Kendall (MK) test is a non-parametric test, commonly used to detect significant trends in hydrological and meteorological time series (e.g., Cannarozzo et al. 2006;