



Temporal and spatial trend detection of maximum air temperature in Iran during 1960–2005



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ARTICLE INFO

Article history:

Received 5 May 2012

29 June 2013

Accepted 16 August 2013

Available online 24 August 2013

Keywords:

climate change

Iran

T max

trend

ABSTRACT

Trends of maximum air temperature (T max) were investigated in three time scales including annual, seasonal, and monthly time series in 32 synoptic stations in the whole of Iran during 1960–2005. First, nonparametric Mann–Kendall test after removal of the lag-1 serial correlation component from the T max time series was used for trend detection and spatial distribution of various trends was mapped. Second, Sen's slope estimator was used to determine the median slope of positive or negative T max trends. Third, 10-year moving average low-pass filter was applied to facilitate the trend analysis and the smoothed time series derived from the mentioned filter were clustered in three clusters for each time series and then were plotted to show their spatial distribution patterns in Iran. Results showed that there are considerable significant positive trends of T max in warm months including April, June, July, August and September and warm seasons. These trends can be found in an annual time scale which indicated almost 50% positive trends. However, cold months and seasons did not exhibit a remarkable significant trend. Although it was rather difficult to detect particular spatial distribution of significant trends, some parts in west, north-east and south-east and central regions of the country showed more positive trends. In an annual time scale, Kermanshah located in west regions indicates most change at (+) 0.41 °C per decade. On the one hand, many clusters of normalized and filtered T max time series revealed the increasing trend after 1970 which has dramatically risen after around 1990. It is in accordance with many other findings for temperature time series from different countries and therefore, it can be generated from simultaneous changes in a bigger scale than regional one. On the other hand, the concentration of increasing trends of T max in warm seasons and their accordance to plants growing season in Iran can raise the importance of the role of frequent reported land use changes during past decades. Generally, the more sophisticated and comprehensive researches are needed to determine the role of different factors such as the emission of greenhouse gases and land use changes influencing temperature trends in Iran.

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1. Introduction

Following the survey of climatic parameter trends such as global average air temperature (e.g. IPCC (2007)), vapor pressure (e.g. Durre et al. (2009)), precipitation (e.g. New et al. (2001)), net radiation (e.g. Wild (2009)), and wind speed (e.g. McVicar et al., 2012), the researchers in Iran have surveyed climatic parameters in different time series especially temperature (Kousari and Asadi Zarch, 2011; Kousari et al., 2011; Tabari et al., 2011; Saboohi et al., 2012), precipitation (Modarres and de Paulo Rodrigues da Silva, 2007; Soltani et al., 2012), drought (Bari Abarghouei et al., 2011), relative humidity (Kousari and Asadi Zarch, 2011; Kousari et al., 2011) and near surface wind speed (Kousari et al., 2013). The results illustrate some trends especially increasing ones for the temperature. Iran is located in one of the most

strategic parts of the world that is Middle East. The Middle East is largely arid to semi-arid and fresh water is often a scarce and precious resource. The combination of a stressed fresh water resource and rapid population growth substantially increases the vulnerability of the region to future climate change (Evans, 2009). While some studies such as the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) points out that the Middle East, which lies in the east of the Mediterranean Basin, is one of the most vulnerable regions to global climate change (Bozkurt and Sen, 2013), the increasing trend of temperature in some parts of Iran and its following possible consequences has resulted in a serious concern for researchers, decision makers and managers.

Temperature is one of the critical variables that drives biological systems and is of fundamental importance in crop growth (Reicosky et al., 1988). Among the various dominant atmospheric variables, temperature has a significant and direct influence on almost all hydrological variables (Sonali and Nagesh Kumar, 2013). However under the condition of climate changes and global warming (IPCC, 2007), temperature

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has been considered more and more than it was in the past. As stated Gadgil and Dhorde (2005), of all the climatic elements, temperature plays a major role in detecting climatic change brought about by urbanization and industrialization.

Increasing and warming of the air temperature have been found across most parts of Iran, including the south, east and south-east of Iran (Kousari et al., 2011). Tabari and Hosseinzadeh Talaei (2011) investigate trends in maximum (T max) and minimum (T min) air temperatures in the annual, seasonal and monthly time-scales for 19 synoptic stations in the arid and semi-arid regions of Iran during 1966–2005. Kousari and Asadi Zarch (2011) showed that there is a significant upward trend in temperature parameter especially for minimum air temperature in arid and semi-arid regions of Iran. The trend in annual T max and T min averaged over all 19 stations was 0.090 and 0.444 °C per decade, respectively. The T max and T min warming trends were more obvious in summer and winter than in autumn and spring. Saboohi et al. (2012) showed that most stations, especially those in western and eastern parts of the country, had significant positive trends in monthly temperature time series in summer season.

Arora et al. (2005) analyzed temperature time series of 125 stations distributed over the whole of India and showed that maximum temperature and mean minimum temperature have increased. In Pakistan, linear trend analysis has shown that there is a clear indication of warming. The increasing rate of temperature has been found to be 0.06 °C per decade (Afzaal et al., 2009). In this country (del Río et al., 2013) showed that temperature has generally increased in Pakistan at all time scales analyzed over the past few decades.

There are different climatic parameters which are associated with temperature and the most common ones are average, maximum and minimum, absolute maximum and absolute minimum air temperatures. Therefore, as part of the effort to understand climate changes, this study was conducted to evaluate the maximum air temperature (T max) trends of the past decades of 32 synoptic meteorological stations located in different parts of Iran. T max was trended by a nonparametric Mann–Kendall test (MK test) spatially and temporally in three time series (annual, seasonal, and monthly). Then, Sen's slope estimator was used to determine the amount of the changes; furthermore, a 10-year moving average low-pass filter was employed on normalized T max time series to facilitate trend analysis during time series. Finally, all normalized and filtered T max time series were clustered, and the trend patterns were mapped. These results and findings can help experts, researchers and decision makers to get more information about the spatial and temporal trends of T max in Iran.

2. Material and methods

2.1. Study area and relevant data

Iran, with about 1,648,000 km² area, is located in the south west of Asia, approximately between 25°00'N and 38°39'N latitudes and between 44°00'E and 63°25'E longitudes. According to Dinpashoh et al. (2011) generally, Iran is categorized as having arid (BW) and semi-arid (BS) climates based on the Koppen climatic classification (Ahrens, 1998). In Iran the main source of water is precipitation, which normally amounts to 251 mm or 413 billion cubic meters annually. This precipitation depth is less than one-third of worldwide average precipitation (831 mm) and about one-third of the average precipitation in Asia (732 mm) (Malekinezhad, 2009). The received precipitation extremely varies spatially and temporally. However, more than 70% of the annual precipitation is lost through evapotranspiration (Kousari and Ahani, 2012). Low amounts of annual precipitation; highly spatial and temporal variation in precipitation in contrast to the tremendous potential of evapotranspiration make Iran a vulnerable country in regard to climate changes and global warming.

The situation of topography in Iran is also striking and plays an exclusive role in the climate of the country. Mountainous basins and plains

are 53 and 47% of the total area of Iran, respectively (Asadi Zarch et al., 2011). There are two main mountain chains in Iran namely Alborz and Zahros. Alborz Mountains extends from the north to the west and east of Iran, while, Zagros Mountains extends from the northwest to the southern part of Iran (Dinpashoh et al., 2011). These mountains play an important role in the distribution of perceptible atmospheric water vapor in Iran and therefore, many central and eastern parts of Iran receive lesser precipitation than northern and westerns areas.

Fig. 1 shows the distribution of 32 synoptic stations used in this study. These stations have a good distribution with a suitable period of weather data (46 years), which can support T max trend studies spatially and temporally. These data have been gathered from 32 synoptic stations of the Iran Meteorological Organization (<http://www.weather.ir>). Table 1 indicates the general characteristics of 32 surveyed stations such as elevation, latitude, longitude and the climate zone status in aspect to aridity (Kousari and Ahani, 2012).

2.2. Trend investigation

2.2.1. Mann–Kendall test

As stated by Duhan and Pandey (2013) there are various parametric and non-parametric tests which were used for identifying trends in hydro-meteorological time series. However, from recent studies it is found that nonparametric tests are mostly used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydrological time series. Non-parametric methods have been frequently used, especially in trend detection, due to their abilities to tolerate outlier data and also they do not need normally distributed time series as input.

The non-parametric rank-based Mann–Kendall test (Mann, 1945; Kendall, 1975) was considered to detect trends of T max values in different time scales. For more details about Mk test see Yue and Wang (2002), Arora et al. (2005), Zhu and Day (2005), Zhang et al. (2006), Chen et al. (2007), Dinpashoh et al. (2011), Tabari et al. (2011), Ahani et al. (2012, 2013) and Kousari et al. (2013). In the presence of a serial correlation in a time series, application of the original MK procedure cannot be recommended for the data set, because the effect of lag-1 serial correlation on trend statistic is a major source of uncertainty. To eliminate the influence of serial correlation on the MK test we removed the lag-1 serial correlation component from the time series prior to applying the MK test to assess the influence of trend. This treatment is called “pre-whitening”. The MK test was then used to detect trends in the residual (or pre-whitened) series (Dinpashoh et al., 2011; Ahani et al., 2012).

2.2.2. Sen's slope estimator

Besides the application of MK test for trend detection, Sen's slope estimator also was used in order to assess the amount of changes of T max values in different time series. As stated by Kahya and Kalaycı (2004), if a time series presents linear trend, the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). Like MK test, Sen's slope estimator is a well-known statistical test. Therefore, the details of these methods have not been presented in this study. More details in regard to these statistical functions can be found in Ahani et al. (2012) and also Dinpashoh et al. (2011). The total change during the observed period was obtained by multiplying the slope by the number of years (Tabari and Hosseinzadeh Talaei, 2011). In this study, Sen's slope estimator was applied on all T max time series.

2.3. Application of 10-year moving average low-pass filter and clustering the time series

It is impossible to show all T max time series in this paper. However, exploring in datasets can reveal important notes about the fluctuations and trends in the time series. Therefore, another approach was pursued

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