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# Long-term trends in tourism climate index scores for 40 stations across Iran: the role of climate change and influence on tourism sustainability

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**Abstract** Tourism is a rapidly growing international sector and relies intrinsically on an amenable climate to attract visitors. Climate change is likely to influence the locations preferred by tourists and the time of year of peak travel. This study investigates the effect of climate change on the Tourism Climate Index (TCI) for Iran. The paper first calculates the monthly TCI for 40 cities across Iran for each year from 1961 to 2010. Changes in the TCI over the study period for each of the cities are then explored. Increases in TCI are observed for at least one station in each month, whilst for some months no decreases occurred. For October, the maximum of 45 % of stations demonstrated significant changes in TCI, whilst for December only 10 % of stations demonstrated change. The stations Kashan, Orumiyeh, Shahrekord, Tabriz, Torbat-e-Heidarieh and Zahedan experienced significant increases in TCI for over 6 months. The beginning of the change in TCI is calculated to have occurred from 1970 to 1980 for all stations. Given the economic dependence on oil exports, the development of sustainable tourism in Iran is of importance. This critically requires the identification of locations most suitable for tourism, now and in the future, to guide strategic investment.

**Keywords** Tourism climate index · Climate change · Iran · Mann-Kendall test · Climate suitability

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## Introduction

The selection of a tourism destination is a decision which is inherently influenced by the local climate (Morgan et al. 2000; Maddison 2001; Perch-Nielsen et al. 2010). Leisure tourism is predominated by decisions which primarily involve the climate of the destination, with clear skies and warm temperatures providing a significant draw-card to visitors of coastal locations, whilst prolonged periods of snow cover are required for skiing (Elsasser and Burki 2002; Hamilton et al. 2005; Burns and Bibbings 2009). Climate dictates the potential for various types of recreation activities, whilst the weather and its associated season controls the periods of peak occupancy (Amelung et al. 2007; Perch-Nielsen et al. 2010). This is particularly the case for business, educational and cultural tourism, which whilst less dependent on optimal climate, is temporally influenced by seasons of optimal climate (Miekzowski 1985; Amelung et al. 2007). For these tourism purposes, where two locations of similar cultural or educational value exist, that which boasts a more attractive climate is more often selected (Miekzowski 1985). The significance of the role of climate in determining the timing and location of tourist preference results in tourist destinations and tourism accommodation establishments prospering when they can use the local climate to their advantage (Belen Gomez Martin 2005; Perch-Nielsen et al. 2010). Furthermore, given the flexibility which tourists have to select different tourist destinations over long periods, and to change their accommodation bookings over short periods, the role of any weather or climate changes in tourist location or timing preference are felt more severely by the tourism accommodation establishment than by tourists (Hein et al. 2009). Critical in the success of such endeavours to maximise tourism potential through the local climate, is the capacity to predict, and adapt to, future climate changes in the particular region, and for the tourism sector to identify key

regions which are likely to become best suited to recreational and business tourism under future climates (Elsasser and Burki 2002; Hamilton et al. 2005; Burns and Bibbings 2009).

The enjoyment of a location on the basis of the climate rests primarily on the thermal comfort of tourists (Lin and Matzarakis 2008; Perch-Nielsen et al. 2010). Locations which are too hot discourage prolonged outdoor activity, whilst those which are too cold or wet prevent such activities entirely, and particularly unfavourable climates will deflect non-leisure tourism to lower risk regions (Miekzowski 1985). In addition to the absolute temperature, the humidity is a key driver of the capacity to withstand high temperatures, and a function of the human climate 'comfort zone' (Amelung and Viner 2006; Perch-Nielsen et al. 2010). Secondary factors include the probability and duration of precipitation, the number of sunshine hours and the intensity of wind (Amelung et al. 2007; Perch-Nielsen et al. 2010). As tourists are likely to be selecting from a range of locations, as well as an optimal time of travel, any changes in these variables would likely reduce the suitability of a location, and reduce its preference (Amelung and Viner 2006). TCIs consider these climatic variables which drive tourism quantitatively, and through computing their projected changes, indicate whether the favourable local climate of a tourist destination is likely to improve or decline over time (Miekzowski 1985; Perry 2000; Amelung et al. 2007). This facilitates the adaptation of existing tourism establishments to continue to draw tourists despite the poor climate, and for development into currently inclement locations which are likely to attract visitors in future (Perry 2000; Perch-Nielsen et al. 2010). Combined with global climate models, data for TCIs can provide quantitative projections of the future impact of climate on tourism (Scott and McBoyle 2001).

Due to a combination of a rich historical heritage extending back over 5000 years, numerous environmental attractions, and a varied climate, Iran receives a small number but broad spectrum of tourists, who visit widely distributed locations (Farajzadeh and Matzarakis 2009; Morakabati 2011). Iran has a total of eight World Heritage sites, including four ancient historical sites and four comprising historical towns and religious sites (Baum and O'Gorman 2010; Mohmmadi et al. 2010). Tourists to the city of Shiraz, a World Heritage site located at the foot of the Zagros Mountains, are attracted primarily to the cultural heritage and archaeology of one of Iran's oldest cities, with the majority of visitors originating from nearby Islamic countries (Aref et al. 2009). The province of Kermanshah in western Iran similarly attracts visitors through its rich history, significant as the home to a vast variety of cultures over time, and the resultant collection of historical monuments dating back to 226 AD (Mohmmadi et al. 2010).The coastal area of Ramsar, located 291 km from Tehran, attracts predominantly leisure tourists (Eshiki and Kaboudi 2012). With the warm waters of the Caspian Sea and a favourable climate, Ramsar serves as one of the key

coastal tourism locations in the country, and attracts both local and international visitors (Eshiki and Kaboudi 2012). The town of Sare'in similarly attracts leisure tourists, with a range of available activities including mineral hot springs, mountain climbing, hiking, and skiing (Zamani-Farahani and Musa 2012). In addition to cultural and leisure tourism, Iran also has a long history of business tourism, particularly from its own citizens, and residents of adjacent regions (Baum and O'Gorman 2010). Despite the significant number and range of tourism attractions in Iran, the country currently attracts less than two million arrivals annually and receives only 5 % of the Islamic tourism market (Morakabati 2011). To sustainably improve and maintain tourism in Iran, adaptation to future climate change is essential (Ahmadi 2012). TCIs have been recognised as a valuable tool to determine anthropogenic shifts such as urban sprawl which may negatively influence ideal tourist climates, to determine how best to improve tourism through targeting regions which are likely to develop and maintain ideal climates and to advertise particularly advantageous tourist seasons (Farajzadeh and Matzarakis 2009; Roshan et al. 2009; Ahmadi 2012; Farajzadeh and Matzarakis 2012). This study develops a long-term average TCI for Iran, long-term average TCIs for 40 stations in Iran, and explores the trends in TCIs over a 50-year period, monthly, seasonally and annually, for each of the cities studied. Patterns in locations and seasons most suitable for tourism are then further investigated.

The aim of this study is to calculate the TCI scores for 40 stations across Iran, both across the study period, and for each of the years. This facilitates the determination of changes in TCI scores, and associated climatic suitability of each region for tourism, over the study period, together with the point at which the change occurred. The climate data for past decades allows for climate projections to determine likely future suitability of each city to tourism. This information produced by this study has the potential to facilitate improved adaptation policies for existing tourism establishments, and for a more informed planning approach to tourism expansion in Iran, to ensure sustainable economic growth within this sector.

## Materials and methods

### Data

To investigate long-term average TCI values and changes in TCI scores in Iran, monthly climate data were obtained from the Iranian Meteorological Organization for the period 1961–2010. The climate data required were selected on the basis of previous TCI studies (Miekzowski 1985; Perch-Nielsen et al. 2010) and include the monthly maximum and average temperature, minimum and average relative humidity, sunshine hours, rainfall and wind speed for 40 synoptic stations. This

group of meteorological stations was selected as those stations had the most complete records among all stations in Iran, with a maximum 5 % omission across the study period. Data reconstruction for any missing data was undertaken using linear regression, with a run-test conducted to ensure data heterogeneity (Alexandersson and Moberg 1997). The distribution of the 40 meteorological stations within Iran is demonstrated in Fig. 1.

## Methods

The TCI used in this study was derived from the original formula developed by Miekzowski (1985)) and adapted by Perch-Nielsen et al. (2010), to include both the theoretical concept of tourist well-being and the availability of climate data globally (Miekzowski 1985). Their formula considers maximum daily temperature and minimum relative humidity, combined to form the daytime thermal comfort (CD); mean temperature and mean relative humidity, combined to form the average thermal comfort (CA); daily sunshine hours (S); daily precipitation (R); and wind speed (W). CD, CA and R are rated on a scale from −3 to 5, S and W are rated on a scale from 0 to 5 (Miekzowski 1985; Perch-Nielsen et al. 2010).

The overall TCI for a location is thus calculated:

$$TCI = 2(4CD + CA + 2R + 2S + W).$$

As each component of the TCI has a maximum score of 5 (Table 1), the values are compared with a total potential score of 100 (Miekzowski 1985; Perch-Nielsen et al. 2010). Acceptable scores are considered be greater than 40, good scores greater than 60, and excellent scores greater than 80 (Perch-Nielsen et al. 2010, Table 2).

In addition to calculating the long-term mean TCI for each of the meteorological stations, this study explores changes in the monthly TCI for the period 1961–2010. Trends, and the change point of these trends, were calculated using the Mann-Kendall test. A statistically significant trend is detected if there is an intersection point between the progressive and backward series produced by the test. The point at which the progressive series [u(t)] intersects the backward series [u′(t)] reveals the time point at which the trend begins. The series [u(t)] is calculated as follows, with a critical value of ±1.96 for the 95 % confidence level:

$$u(t) = \frac{t_j - e_{(t)}}{\sqrt{\mathrm{var}(t_j)}}$$

**Fig. 1** Map indicating the location and distribution of the studied stations
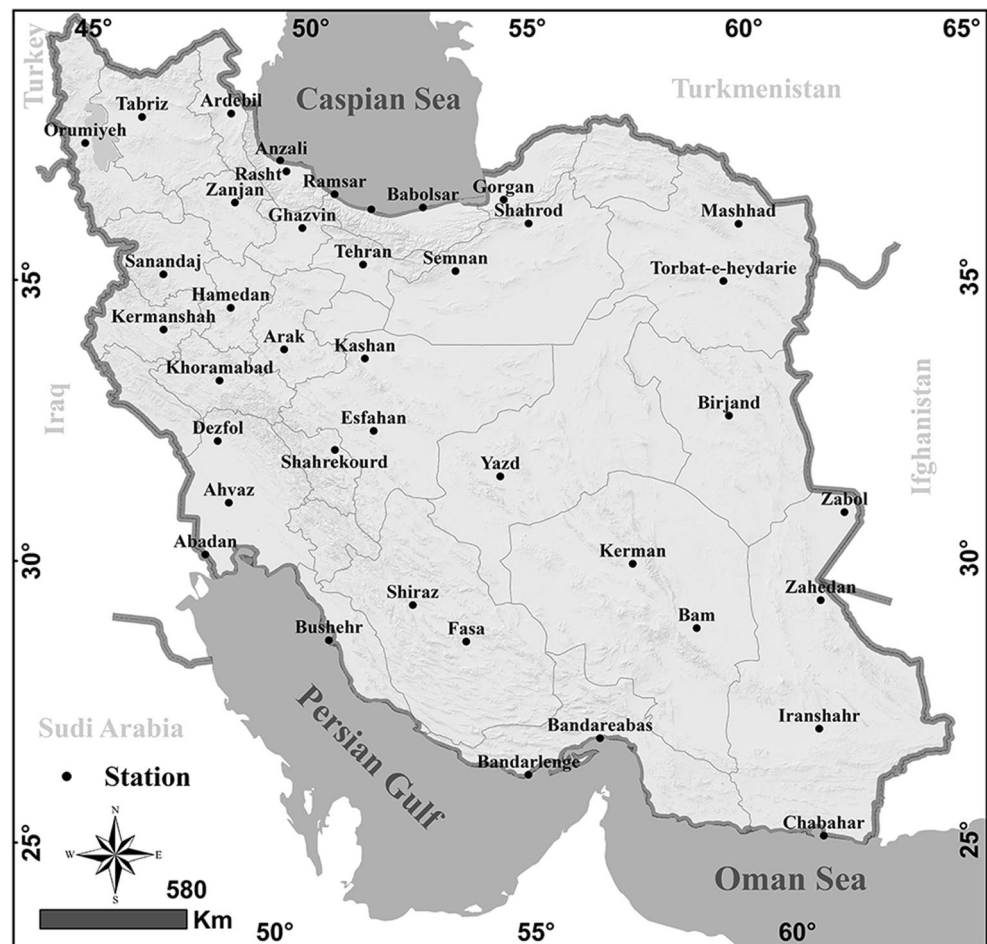
**Table 1** Ratings of each of the climate variables for use in the TCI (adapted from Miekzowski 1985)

| Rating | Effective temperature (°C) | Mean monthly precipitation (mm) | Mean monthly sunshine hours (h day$^{-1}$) | Wind speed (km h$^{-1}$) | | | Wind (W m$^{-1}$ h$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | Normal | Trade wind | Hot climate | |
| 5.0 | 20–26 | 0.0–14.9 | >10 | <2.88–5.75 | 12.24–19.79 | | |
| 4.5 | 19 27 | 15.0–29.9 | 9 | 5.76–9.03 | 9.04–12.23 19.80–24.29 | | |
| 4.0 | 18 28 | 30.0–44.9 | 8 | 9.04–12.23 | | | <500 |
| 3.5 | 17 29 | 45.0–59.0 | 7 | 12.24–19.79 | 5.76–9.03 24.30–28.79 | | |
| 3.0 | 16 30 | 60.0–74.9 | 6 | 19.80–24.29 | 2.88–5.75 | | 500–625 |
| 2.5 | 10–15 31 | 75.0–89.9 | 5 | 24.30–28.79 | <2.88 28.8–38.52 | | |
| 2.0 | 5–9 32 | 90.0–104.9 | 4 | 28.8–38.52 | | <2.88 | 635–750 |
| 1.5 | 0–4 33 | 105.0–119.9 | 3 | | | 2.88–5.75 | 750–875 |
| 1.0 | (−)5–(−)1 34 | 120.0–134.9 | 2 | | | 5.76–9.03 | 875–1000 |
| 0.5 | 35 | 135.0–49.9 | 1 | | | 9.04–12.23 | 1000–1125 |
| 0.25 | | | | | | | 1125–1250 |
| 0 | >36 (−)10–(−)6 | >150.0 | <1 | >38.52 | >38.52 | >12.24 | >1250 |
| −1.0 | (−)15–(−)11 | | | | | | |
| −2.0 | (−)20–(−)16 | | | | | | |
| −3.0 | <(−)20 | | | | | | |

Where: $n$=number of cases

$$t_j = \sum_1^j n_j e(t) = \frac{n(n-1)}{4} \mathrm{var}(t_j) = \frac{j(j-1)(2j+5)}{72}$$

To determine the significance of the trend, the Mann-Kendall rank test is used, comparing the test statistic $\tau$ against $(\tau)_t$ with a $t_\tau$ representing the desired probability of the Gaussian normal distribution, taken at 0.05.

$$\tau = \frac{4P}{N(N-1)} - 1$$

and

$$(\tau)_t = 0 \pm \tau_g \sqrt{\frac{4N+10}{9N(N-1)}}$$

Where: $N$=largest $v$

$$P = \sum_{i=1}^{N-1} n_1$$

Daily data were used to determine the frequency of extreme events including heat stress, heavy precipitation and high winds. Whilst these are not included in the TCI, their occurrence would make the environment unsuitable for tourists and would comprise an additional impact of climate change on tourism.

To evaluate the role of climate change on TCI score changes for future decades, atmospheric values were simulated

**Table 2** Rating categories of the output score of the TCI (after Perch-Nielsen et al. 2010)

| TCI Score | Category | Mapping Category |
|---|---|---|
| 90–100 | Ideal | Excellent |
| 80–89 | Excellent | |
| 70–79 | Very good | Very Good and Good |
| 60–69 | Good | |
| 50–59 | Acceptable | Acceptable |
| 40–49 | Marginal | |
| 30–39 | Unfavourable | Unfavourable |
| 20–29 | Very unfavourable | |
| 10–19 | Extremely unfavourable | |
| <10 | Impossible | |

using the Hadcm3 general circulation model based on the A2 scenario, using model data acquired from the CCDS in September 2013 (CCDS 2013). This scenario was chosen because Iran is among the top ten countries for carbon dioxide emissions (Nejat et al. 2014). As high-resolution data was required to calculate future TCI scores, the LARS_WG 5.5 model was used to downscale the output. The model was then compared with the observed data for past decades, and for all stations, the results confirm a good and acceptable matching between simulated and actual data.

## Results

As this study analyses monthly time-series for each of the stations, the changes in TCI over the study period will be discussed in groups of seasons and their respective months. Due to differences between the Persian and Western calendars, slight adjustments in the classification of seasons have been made.

### Winter

December is the first month of winter in Iran; most areas in Iran experience cold and rainy weather. The climate is influenced predominantly by the Siberian high from the north-east and low pressure cells from the northwest. Climate is particularly unfavourable for tourism in cities on the Caspian coast, due to increased cloud cover and precipitation. By contrast, cities in the south have a particularly favourable climate, as the winter months have sufficiently cool climates and clear skies to attract tourists. The long-term TCI average for December is relatively low, categorised as good at 60. Minimum TCI averages are observed for Anzali at 39.4 and Rasht at 49.3.

Maximum values of 88.9 and 86.8 TCI units are calculated for Chabahar and Bandar Lengeh, respectively. The smallest group of stations (10 %) are categorised in the ideal to excellent category, whilst 55 % of stations are categorised as marginal to acceptable and 35 % as good to very good (Fig. 2). Increasing trends of TCI values are observed for 12.5 % of stations, with largest rates of change of 1.01 TCI units per decade ($t=0.381$) for Ardebil. Decreasing trends in TCI values are observed for 5 % of stations, with a rapid rate of change of 2.8 TCI units per decade ($t=-0.256$) for Semnan.

The long-term average TCI for January is calculated at an even lower 56, which is classified as acceptable for tourism (Table 2). Comparing the individual meteorological stations, the long-term average TCI values range from an unfavourable 38 for Anzali to an excellent 88 for Chabahar, with 35 % of stations in unfavourable to marginal quality limits (TCI=30 to 49), 52.5 % of the stations in the acceptable and good-quality limits (TCI=50 to 69) and 12.5 % of the stations are in the very good to excellent limits (TCI=70–89). Approximately 20 % of stations demonstrated a significant increasing trend in TCI scores over the study period. The largest increase in TCI was observed for the station Sanandaj, at a rate of a 2.42 TCI score increase per decade ($t=0.296$) (Table 4). Only 5 % of stations reveal decreasing TCI scores, ranging from 0.41 TCI score per decade ($t=-0.228$) for Orumiyeh to 1.73 TCI score per decade ($t=-0.224$) for Noshahr (Fig. 3).

The long-term average TCI for February was calculated at 61.30. This increase of five units from January places the TCI for February back in the good category. There is a similar level of spatial variation in long-term TCI values, ranging from 90.8 in Chabahar and 40.26 in Anzali. Over the study period, 40 % of stations demonstrated increasing TCI scores, with rates of



**Fig. 2** TCI ratings averaged for the country of Iran over the period 1961–2010
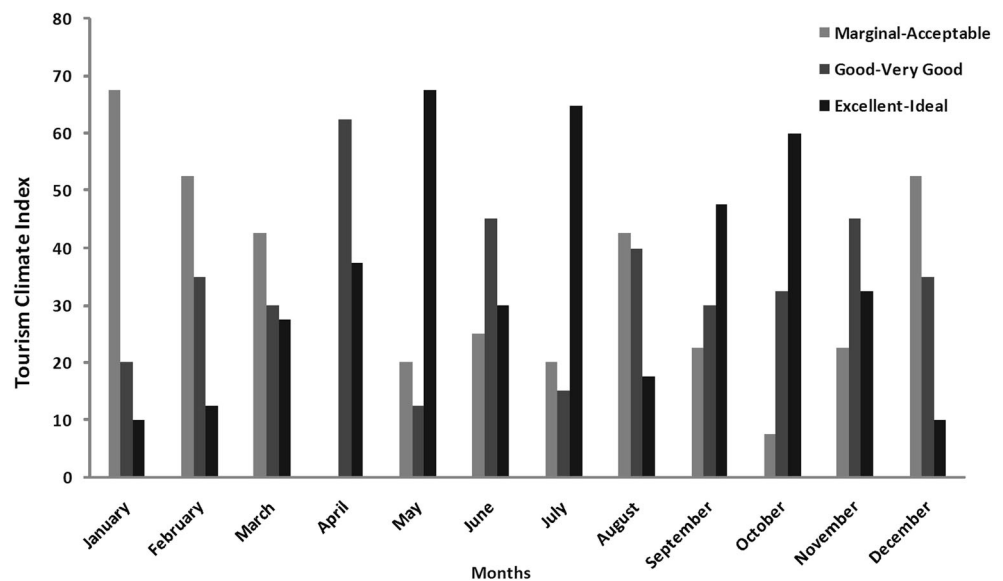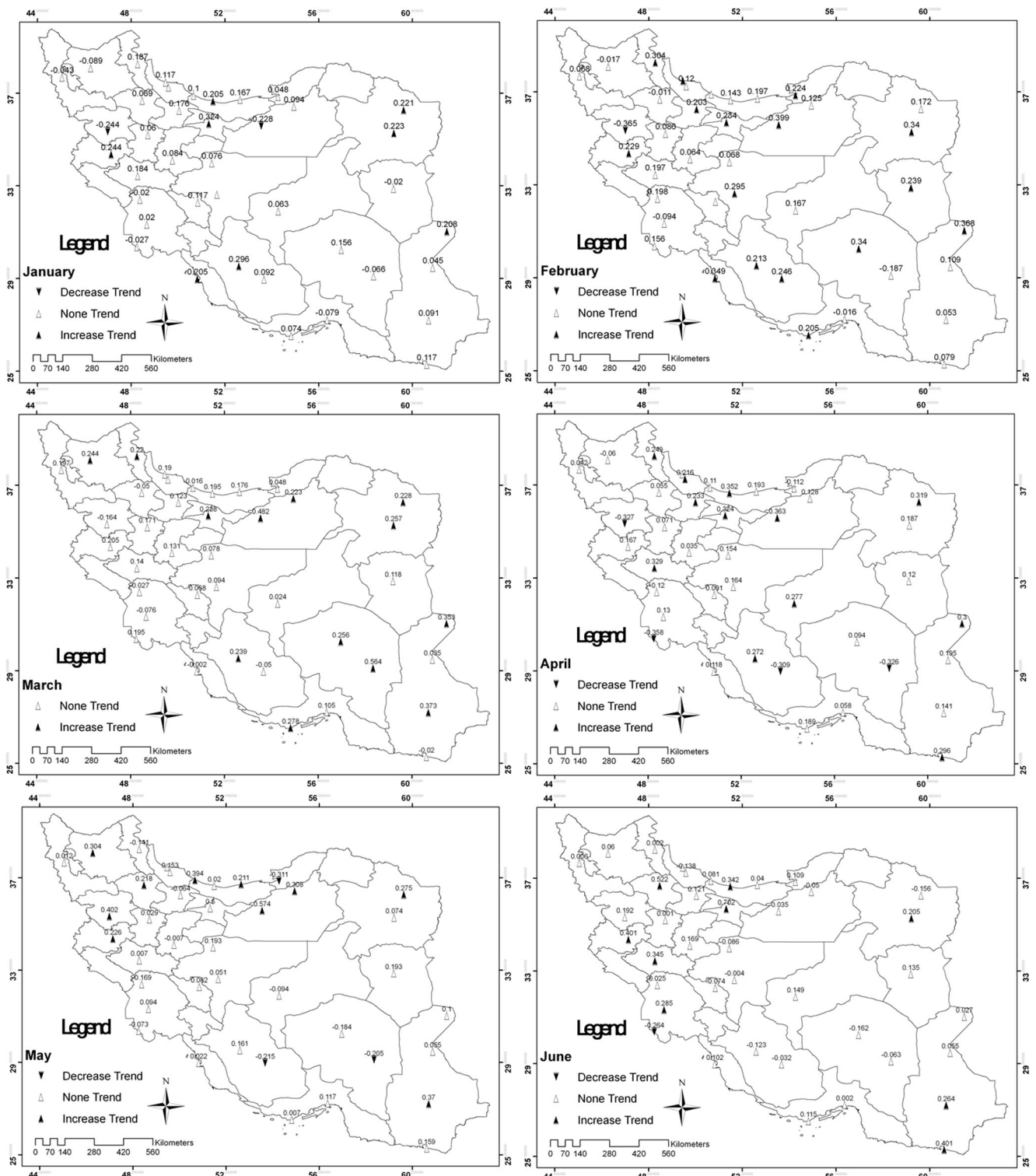
**Fig. 3** Evaluating the significant trend of TCI index based on the Mann-Kendall test for the studied stations

change as large as 2.48 TCI score per decade ($t=0.224$) for Fasa and 2.33 TCI score per decade ($t=0.340$) for Iranshahr. Only the station of Noshahr demonstrated a significant decreasing trend of 1.87 TCI score per decade ($t=-0.365$) (Fig. 2).

**Spring**

Spring is associated with a decrease in precipitation and warmer temperatures, with more favourable conditions experienced across much of the country. The Caspian coast remains
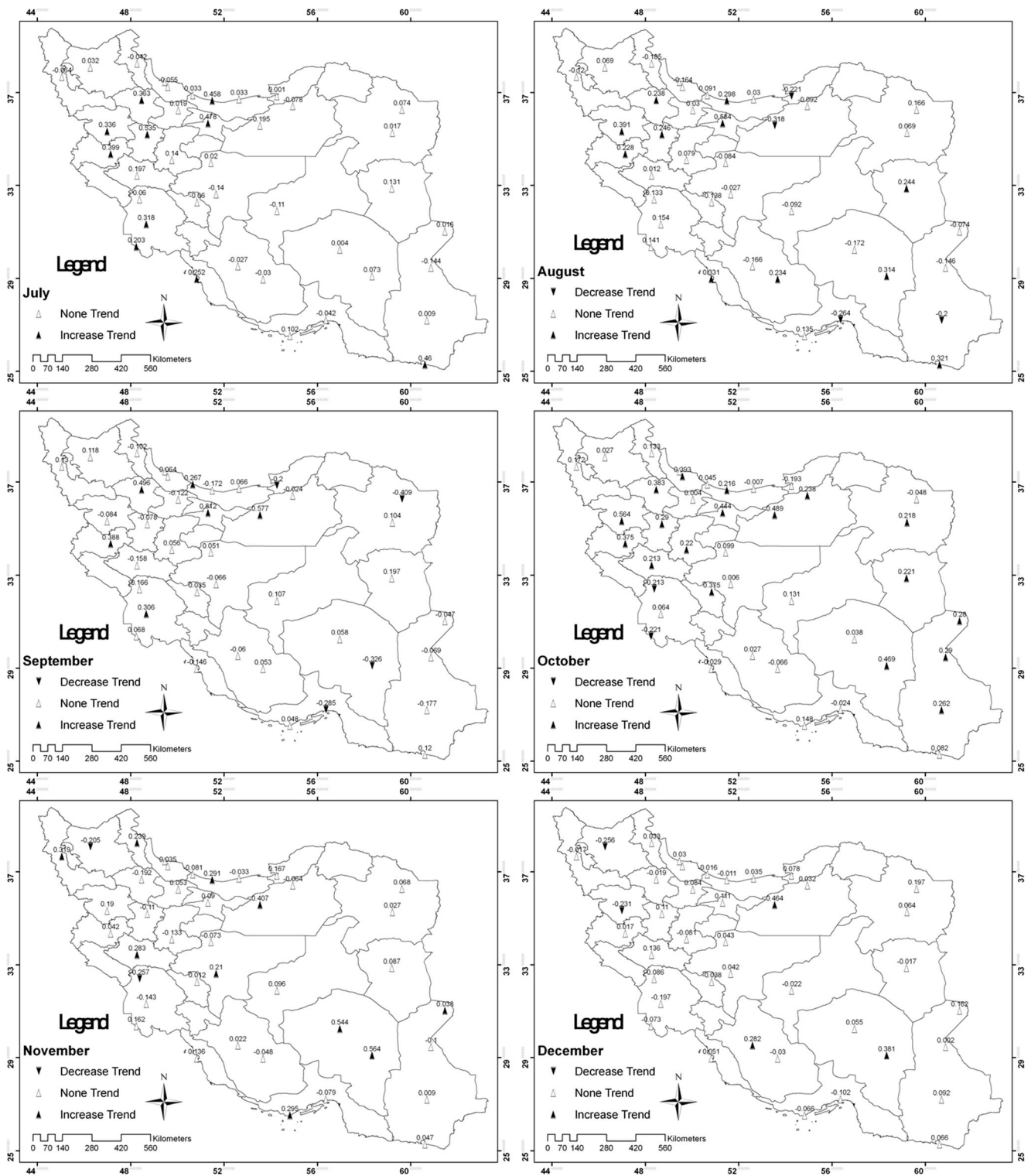
**Fig. 3** (continued)

unfavourable with significant precipitation due to the dominant westerlies, whilst a subtropical high pressure dominates over the southern region. March has a long-term TCI score average for the 40 stations of 66.70, an increase of 5.4 units from February. The lowest TCI value for March is now in the acceptable category at 44.5 for the Anzali station, whilst the maximum value of 88.6 is calculated for Abadan (Table 3). For March, 42.5 % of the stations have experienced marginal to acceptable (TCI=40 to 59) values, a 10 % decrease from February. The good to very good category for March includes 30 % of the stations, which

**Table 3** Long-term average TCI values for each of the climate stations for the period 1961–2010

| Stations | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | 67.8 | 80.5 | 88.6 | 76.2 | 51.7 | 43.3 | 51.7 | 41.4 | 44.4 | 59.1 | 85.0 | 74.5 |
| Ahvaz | 63.8 | 78.5 | 85.0 | 75.2 | 52.8 | 44.2 | 52.8 | 42.5 | 45.5 | 62.5 | 83.7 | 71.0 |
| Anzali | 38.4 | 40.3 | 44.5 | 60.5 | 81.8 | 77.4 | 81.8 | 58.6 | 63.1 | 64.1 | 46.5 | 39.4 |
| Arak | 46.6 | 52.9 | 58.1 | 73.9 | 87.5 | 83.2 | 87.5 | 73.8 | 88.8 | 86.5 | 62.9 | 51.2 |
| Ardebil | 45.8 | 49.1 | 51.5 | 69.5 | 82.0 | 91.0 | 82.0 | 87.4 | 86.5 | 66.3 | 52.0 | 46.3 |
| Babolsar | 47.7 | 50.8 | 53.3 | 71.9 | 87.7 | 75.2 | 87.7 | 56.2 | 61.1 | 72.9 | 59.0 | 48.2 |
| Bam | 70.8 | 79.7 | 87.7 | 86.6 | 67.1 | 55.9 | 67.1 | 58.8 | 69.3 | 87.6 | 90.4 | 77.9 |
| Bandarabas | 82.4 | 84.9 | 80.5 | 69.5 | 46.0 | 41.1 | 46.0 | 43.3 | 40.1 | 50.3 | 78.6 | 85.4 |
| Bandarlenge | 83.5 | 87.1 | 86.8 | 73.6 | 51.1 | 42.3 | 51.1 | 44.0 | 41.6 | 56.9 | 82.5 | 86.8 |
| Birjand | 58.2 | 60.6 | 70.7 | 86.1 | 89.4 | 72.9 | 89.4 | 75.7 | 87.6 | 90.0 | 80.1 | 61.5 |
| Bushehr | 67.8 | 78.4 | 86.4 | 82.2 | 58.7 | 48.3 | 58.7 | 43.1 | 43.7 | 62.5 | 84.8 | 73.6 |
| Chabahar | 87.6 | 90.8 | 83.3 | 70.5 | 55.8 | 58.3 | 55.8 | 53.7 | 57.9 | 61.2 | 79.0 | 88.9 |
| Dezful | 57.9 | 72.1 | 78.7 | 75.8 | 55.9 | 45.6 | 55.9 | 44.1 | 50.1 | 63.8 | 77.0 | 64.5 |
| Esfahan | 59.8 | 64.1 | 69.9 | 86.5 | 94.1 | 75.6 | 94.1 | 70.3 | 86.9 | 90.0 | 71.4 | 61.4 |
| Fasa | 57.3 | 67.3 | 77.6 | 87.6 | 80.7 | 65.0 | 70 | 61.6 | 73.2 | 88.6 | 85.4 | 66.0 |
| Ghazvin | 49.8 | 53.4 | 58.0 | 76.1 | 88.0 | 82.5 | 88.0 | 70.5 | 87.1 | 85.6 | 63.7 | 52.0 |
| Gorgan | 55.7 | 55.8 | 55.8 | 76.7 | 77.7 | 65.3 | 77.7 | 52.1 | 64.9 | 78.2 | 70.9 | 56.7 |
| Hamedan | 41.3 | 45.4 | 53.7 | 68.0 | 85.5 | 88.5 | 85.5 | 74.5 | 90.1 | 83.2 | 58.9 | 46.2 |
| Iranshahr | 81.8 | 86.3 | 84.4 | 68.3 | 52.2 | 44.1 | 52.2 | 43.6 | 52.8 | 68.6 | 88.4 | 86.3 |
| Kashan | 57.9 | 64.7 | 75.6 | 85.7 | 77.9 | 62.3 | 77.9 | 56.2 | 71.7 | 86.5 | 76.1 | 61.8 |
| Kerman | 58.1 | 62.4 | 71.9 | 86.7 | 91.2 | 74.2 | 91.2 | 76.7 | 87.8 | 89.2 | 80.7 | 63.4 |
| Kermanshah | 44.5 | 48.5 | 54.3 | 72.9 | 87.9 | 77.3 | 87.9 | 64.9 | 83.2 | 84.2 | 64.1 | 50.1 |
| Khoramabad | 50.9 | 56.2 | 61.7 | 78.5 | 84.9 | 69.6 | 84.9 | 60.8 | 73.1 | 85.4 | 72.1 | 52.7 |
| Mashhad | 51.7 | 53.6 | 56.7 | 77.8 | 89.0 | 79.9 | 89.0 | 78.1 | 91.4 | 86.9 | 67.6 | 56.1 |
| Noshahr | 47.1 | 48.3 | 48.0 | 62.9 | 80.5 | 75.1 | 80.5 | 54.4 | 61.5 | 63.5 | 50.1 | 45.7 |
| Orumiyeh | 48.1 | 49.6 | 54.2 | 64.6 | 81.8 | 91.8 | 81.8 | 85.1 | 90.4 | 76.0 | 55.9 | 48.1 |
| Ramsar | 47.5 | 47.2 | 47.4 | 59.7 | 79.2 | 75.2 | 79.2 | 58.5 | 61.1 | 65.8 | 51.9 | 47.8 |
| Rasht | 42.2 | 44.1 | 46.5 | 69.0 | 79.7 | 70.6 | 79.7 | 52.7 | 58.6 | 64.3 | 51.7 | 43.9 |
| Sanandaj | 43.9 | 48.3 | 54.4 | 70.7 | 85.9 | 82.4 | 85.9 | 69.1 | 86.2 | 83.9 | 60.9 | 49.9 |
| Semnan | 57.3 | 60.9 | 69.1 | 86.9 | 85.7 | 69.6 | 85.7 | 63.3 | 80.6 | 89.5 | 72.5 | 59.2 |
| Shahrekord | 48.8 | 55.0 | 58.9 | 72.0 | 88.8 | 84.6 | 88.8 | 79.3 | 88.5 | 87.2 | 64.2 | 51.5 |
| Shahroud | 52.2 | 57.3 | 63.3 | 81.9 | 90.5 | 85.9 | 90.5 | 79.6 | 91.3 | 87.8 | 66.7 | 55.3 |
| Shiraz | 54.2 | 61.8 | 71.5 | 86.9 | 89.4 | 70.0 | 89.4 | 65.4 | 76.8 | 91.7 | 81.7 | 60.2 |
| Tabriz | 42.1 | 47.6 | 53.3 | 64.4 | 84.6 | 93.9 | 84.6 | 81.0 | 95.4 | 80.8 | 59.5 | 47.7 |
| Tehran | 51.6 | 54.5 | 63.0 | 82.5 | 93.8 | 75.4 | 93.8 | 66.9 | 86.1 | 89.5 | 67.5 | 55.4 |
| Torbat-e-Heidarieh | 50.6 | 54.3 | 60.7 | 80.4 | 92.3 | 83.8 | 92.3 | 84.5 | 90.9 | 87.4 | 68.5 | 55.5 |
| Yazd | 60.5 | 68.7 | 80.4 | 90.5 | 83.3 | 65.1 | 73.3 | 64.7 | 76.3 | 91.9 | 81.7 | 64.5 |
| Zabol | 64.8 | 74.9 | 85.8 | 81.9 | 63.0 | 50.4 | 63.0 | 51.6 | 65.3 | 89.1 | 86.7 | 70.0 |
| Zahedan | 61.4 | 68.3 | 82.5 | 92.7 | 82.4 | 68.1 | 82.4 | 69.9 | 84.6 | 91.0 | 86.9 | 67.6 |
| Zanjan | 44.8 | 48.2 | 54.4 | 66.3 | 83.4 | 92.3 | 83.4 | 82.8 | 90.8 | 80.6 | 56.8 | 49.4 |
| Total average | 56.1 | 61.3 | 66.7 | 76.2 | 78.0 | 69.9 | 78.0 | 63.5 | 73.2 | 78.3 | 70.6 | 59.9 |

represents a 5 % decrease from that of February. Notably, the excellent category (TCI=80 to 89) for March includes 27 % of stations, which represents a 15 % increase from February. This is largely expected moving out of the winter season. None of the stations demonstrates a significant decrease in the TCI values over the study site. Significant increasing trends are observed

for 35.5 % of the cities, with particularly strong increases, such as 2.93 units per decade for Ardabil ($t$=0.564), 2.93 units per decade for Kermanshah ($t$=0.228) and 2.90 units per decade for Sanandaj ($t$=0.239) (Fig. 3).

The second month of spring coincides with the Iranian New Year, which is one of the busiest tourist seasons across

Iran. Thus, any changes in the TCI during this period are of particular importance. The long-term average TCI across the 40 stations for April is categorised as good, with a value of 76. The lowest TCI values are calculated for the coastal cities in the northern Provinces, including Ramsar at 59.6, Anzali and 60.5 and Noshahr at 63. The maximum TCI values are observed for the southern region of Iran, including excellent categories for Zahedan at 93, Yazd at 90.5 and Fasa at 87.6. For April, 27.5 % of the stations had good category values (TCI=60 to 69), 35 % had very good category values (TCI= 70 to 79) and 37.5 % had excellent to ideal category values (TCI=80 to 100) (Table 3). Of benefit to tourism in this important period, 30 % of stations demonstrate an increasing TCI trend over the study period, with magnitudes as large as 3.38 TCI units per decade ($t$=0.272) for Sanandaj and 3.25 TCI units per decade (t=0.319) for Kermanshah. Only 10 % of stations demonstrated decreasing trends in TCI values, yet those which do remain of concern with rates of change as large as 4 TCI units per decade ($t$=−0.358) for Abadan.

The long-term TCI average for May across the 40 stations increases slightly from that of April to 78. The lowest TCI values for May are, however, considerably lower than for April, including 51 for Bandar Lengeh, 51.7 for Abadan and 52 for Iranshahr, and are distributed across the southern coastal cities which for the previous month demonstrated the strongest TCI values. The maximum TCI values for May are particularly high, at 92 for Torbat-e-Heidarieh, 93.8 for the capital, Tehran, and 94.5 for Esfahan. For May, 20 % of stations have long-term TCI values in the marginal to acceptable category (TCI=40 to 59), 12.5 % in the good to very good category (TCI=60 to 79) and 67.5 % in the excellent to ideal category (TCI=80 to 100). Evaluating the impact of climate change on TCI index changes in May, 25 % demonstrate significant increasing trends in TCI values, with rates of change as large as 3.51 TCI units per decade for Orumiyeh ($t$=0.574) and 3.43 TCI units per decade for Khoramabad ($t$= 0.394). Only 7.5 % of stations experienced a significant decreasing trend of TCI units, ranging from 3.27 units per decade ($t$=−0.311) for Fasa to 1.35 TCI units per decade for Dezful (t=−0.215) (Fig. 3; Table 4).

**Summer**

In summer, the most favourable locations for tourism, based on climate, shift from the south to the north. Due to the predominance of the Subtropical High, cities in the south become intolerably hot and humid, whilst the regions in the north have a season of clear skies and pleasant temperatures due to their higher latitude and altitude. June has a long-term average TCI of 70, which represents a decrease compared with the spring months. This is due to an increase in temperature beyond the comfort threshold. In this month of the year, the minimum TCI values are again observed for the southern region of Iran,

including 41 for Bandar Abbas, 42 for Bandar Lengeh, 43 for Abadan, 44 for Iranshahr and 44.2 for Ahvaz. The highest TCI values are observed for stations in the west and northwest of Iran, including particularly high, ideal category, values of 91 for Ardabil, 91.8 for Orumiyeh, 92.3 for Zanjan and 94 for Tabriz (Table 2). For the month of June, 25 % of stations are categorised as marginal to acceptable; 45 % as good to very good category; and 30 % as excellent to ideal. For 25 % of stations, an increasing trend in TCI values is observed, although with relatively low maximum rates of change observed, including 2.95 TCI units per decade ($t$=0.522) for Heidarieh and 2.15 TCI units per decade ($t$=0.702) for Shahrekord (Table 4). Only the station of Abadan demonstrated a decrease in TCI values, at a small rate of 0.65 TCI units per decade ($t$=−0.264).

The long-term average TCI for July is categorised as good, at 78. The highest TCI values are calculated for Esfahan at 94 and Tehran at 93.8, whilst the lowest TCI values are found for Bandar Abbas at 46 and Bandar Lengeh at 51.1. Marginal to acceptable TCI values were calculated for 20 % of stations, whilst 15 % fell in the good to very good category, and a substantial 65 % of stations in the excellent to ideal category. Across the study period, increases in TCI are observed for 25 % of stations, with a maximum rate of change of 1.85 TCI units/decade ($t$=0.460) for Birjand and 1.63 TCI units per decade ($t$=0.363) for Torbat-e-Heidarieh. Notably for July, no stations demonstrated significant decreasing trends in TCI scores.

The TCI for August is 14.5 units lower than that of July but remains categorised as good at 63.5. The highest values of 87.4 and 85.1 are observed for the stations at Ardabil and Torbat-e-Heidarieh, respectively, whilst the lowest TCI values are calculated for Abadan at 42.4 units and Ahvaz at 42.5 units. A larger proportion of stations fall into the marginal to acceptable categories for August than July at 42.5 %, whilst 25 % increase in stations categorised as good to very good has similarly occurred. These increases in the marginal to acceptable, and good to very good categories have resulted in a significant decline in stations categorised as excellent to ideal to only 17.5 %. In contrast to the results for July, 10 % of stations reflect decreasing trends in TCI values for August over the study period, with a maximum rate of 1.93 TCI units per decade ($t$=−0.318) observed for the city of Orumiyeh. Increasing trends in TCI values over the study period are observed for 27.5 % of stations, with a maximum rate of change of 1.64 TCI units per decade ($t$=0.336) for Noshahr (Table 4).

**Autumn**

Autumn marks the beginning of the cold period in Iran and the onset of rainfall, particularly in the west and northwest. September has a long-term TCI average of 10 units greater than that for August, placing it in the very good category. TCI

**Table 4** Statistically significant rates of change of TCI units over the period 1961–2010 for each of the climate stations

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | * | * | * | −4.00 | * | −0.65 | −0.25 | * | * | −2.23 | * | * |
| Ahvaz | * | 1.88 | * | * | * | * | * | * | * | * | * | * |
| Anzali | * | * | * | * | * | * | * | * | * | 1.70 | * | * |
| Arak | * | * | * | * | 0.82 | * | * | * | * | * | * | * |
| Ardebil | * | * | 2.93 | −2.52 | −1.77 | * | * | 0.45 | −1.22 | 2.52 | 3.35 | 1.01 |
| Babolsar | * | * | * | * | * | * | * | −1.50 | −1.90 | * | * | * |
| Bam | * | 1.18 | 1.15 | * | * | * | * | * | * | * | 0.40 | * |
| Bandarabas | * | 1.13 | * | * | * | * | * | 0.40 | * | 1.10 | * | * |
| Bandarlenge | 0.93 | 1.18 | * | * | * | * | 1.28 | 0.67 | * | * | * | * |
| Birjand | * | * | * | 0.85 | * | 0.35 | 1.85 | −0.63 | * | * | * | * |
| Bushehr | * | * | * | * | * | * | * | * | * | −2.55 | −1.23 | * |
| Chabahar | * | 0.75 | * | * | * | * | * | * | * | * | −0.13 | * |
| Dezful | * | 1.83 | * | −2.60 | −1.35 | * | * | 0.30 | * | * | * | * |
| Esfahan | * | 0.38 | * | 0.88 | * | * | * | * | * | * | * | * |
| Fasa | * | 2.48 | * | * | −3.27 | * | * | −1.77 | −1.80 | * | * | * |
| Ghazvin | * | * | * | * | * | * | −0.13 | −0.23 | * | 0.33 | * | * |
| Gorgan | * | * | 2.45 | * | 1.48 | 0.75 | * | −1.60 | * | 1.30 | * | * |
| Hamedan | * | * | * | * | * | * | * | * | * | * | * | * |
| Iranshahr | * | 2.33 | 1.78 | * | * | * | * | * | * | * | 2.45 | * |
| Kashan | 0.80 | 0.81 | * | * | 0.75 | 2.05 | 1.40 | 0.98 | 0.93 | 0.84 | * | * |
| Kerman | * | * | * | 1.53 | * | 0.52 | * | * | * | −0.05 | 2.13 | * |
| Kermanshah | 1.90 | * | 2.93 | 3.25 | 1.25 | * | * | * | −2.68 | * | * | * |
| Khoramabad | * | * | * | * | 3.43 | * | * | * | 1.55 | * | * | * |
| Mashhad | * | * | * | 2.13 | * | * | * | * | * | 1.30 | * | * |
| Noshahr | −1.73 | −1.87 | * | −2.63 | 1.03 | * | 0.98 | 1.64 | * | 2.03 | * | −1.71 |
| Orumiyeh | −0.41 | 0.91 | 2.40 | 1.94 | 3.51 | * | * | −1.93 | 0.94 | 2.93 | 1.47 | 0.84 |
| Ramsar | * | * | * | * | * | * | * | * | * | 2.45 | * | * |
| Rasht | * | * | 2.45 | * | 0.50 | * | * | * | * | 1.18 | * | * |
| Sanandaj | 2.40 | 0.63 | 2.90 | 3.38 | 0.161 | * | * | * | * | * | * | 0.78 |
| Semnan | | * | 2.68 | * | 1.78 | * | * | * | * | * | −1.93 | −2.80 |
| Shahrekord | 0.13 | −0.93 | 0.60 | 0.85 | * | 2.15 | 0.57 | 0.10 | 1.13 | 0.02 | * | * |
| Shahroud | 0.98 | 1.75 | 1.98 | * | * | 0.20 | * | * | * | 0.43 | * | * |
| Shiraz | * | * | * | 1.25 | * | * | * | * | * | * | * | * |
| Tabriz | 0.88 | 1.60 | 2.28 | 2.55 | * | * | * | * | * | 2.18 | −0.57 | * |
| Tehran | * | * | * | * | * | * | * | * | * | 0.73 | * | * |
| Torbat-e-Heidarieh | * | * | * | * | 0.80 | 2.95 | 1.63 | 1.15 | 2.48 | 1.23 | * | * |
| Yazd | * | 1.38 | 1.48 | 0.28 | * | * | * | * | * | * | 0.75 | * |
| Zabol | * | * | * | * | * | * | * | * | * | * | 0.95 | * |
| Zahedan | 0.08 | * | * | 1.00 | * | 0.30 | −0.15 | 0.18 | * | 0.18 | −1.06 | * |
| Zanjan | * | * | * | * | * | 0.69 | 0.40 | * | 0.24 | * | * | * |

*Months and stations with non-significant change

values vary spatially from maxima of 95.4 for Tabriz and 91.4 for Mashhad to minima of 40 and 41.6 for Bandar Abbas and Bandar Lengeh, respectively. Similar to July, the largest number of stations fall into the excellent to ideal categories (47.5 %), whilst 30 % of stations are categorised as good to very good and 22.5 % as marginal to acceptable. Over the study period, 10 % of stations demonstrate trends of decreasing TCI values, with a maximum of 2.68 TCI units per decade ($t=-0.409$) for Kermanshah. Trends towards increasing TCI values are observed for 15 % of stations, with a maximum rate of change of 2.48 TCI units per decade ($t=0.496$) for Torbat-e-Heidarieh (Table 4).

The long-term average TCI value for October is categorised as excellent at 78.3. Minimum TCI values are observed for Bandar Abbas at 50.3 TCI units and Bandar Lengeh at 56.9 units. The highest TCI values are calculated for Yazd at 91.9 and Shiraz at 91.7, both of which fall into the ideal category. A considerable 60 % of stations are categorised as excellent to ideal for the month of October. Only 7.5 % of stations are categorised as good to very good, whilst 32.5 % of stations are categorised as acceptable to good. Only 5 % of stations demonstrate decreasing trends in TCI values over the study period, with rates of change of 2.53 TCI units per decade ($t=-0.213$) for Bushehr and 2.23 TCI units per decade ($t=0.221$) for Abadan. Increasing trends in TCI values are observed for 45 % of stations, with maximum rates of change of 2.93 TCI units per decade ($t=0.489$) for Orumiyeh and 2.52 TCI units per decade ($t=0.469$) for Ardabil (Fig. 3).

The long-term TCI value for November is 7.5 units lower than that of October. Minimum TCI values are calculate for Anzali (46.5) and Noshahr (50.1), whilst maximum TCI values are observed for Bam at 90.4 and Iranshahr at 88.4. The largest proportion of stations fall into the good to very good category (45 %), whilst 32.5 % are categorised as excellent to ideal and 22.5 % in the marginal to acceptable category. Over the study period, 25 % of stations demonstrate trends towards increasing TCI values, with a maximum rate of change of 3.35 TCI units per decade ($t=0.564$) for Ardebil (Table 4). Trends of decreasing TCI values are observed for 5 % of the stations, which include Bushehr at 1.23 TCI units per decade ($t=-0.257$) and Semnan at 1.93 TCI units per decade ($t=-0.205$).

**Influence of extreme events**

*Heat stress*

To determine periods of heat stress, the thermal comfort index physiologically equivalent temperature (PET) was used, for the period 1961–2010 for a selection of cities for which daily data were available (Table 5). This index describes the influence of the temperature of air surrounding the human body, through the energy exchange between humans and the environment in both warm and cold environments (Mayer and Höppe 1987; Höppe 1999; Matzarakis et al. 1999). Thermal aspects of PET include thermal acceptability (PET between 18 and 29 °C), heat stress (PET >35 °C) and cold stress (PET <8 °C) (Table 5). The two cities on the Persian Gulf, Bandar Abbas and Abadan experienced heat stress most frequently, at an average of 39.44 and 10.51 % of the days of the year. Other cities which experienced heat stress more seldom are Isfahan, Tabriz, Kermanshah and Mashhad. The city of Yazd has no experience of heat stress. Cold stress most commonly occurred in Tabriz with 26.6 % of days of the year, Kermanshah with 23.6 % and Mashhad with 23 %. Bandar Abbas had no

**Table 5** The percentage of daily frequency of thresholds of thermal acceptance, cold and heat stress for some major cities of Iran

| Station | Total annual average of heat stress in(in percent) | Total annual average of cold stress(in percent) | Total average of thermal acceptance |
|---|---|---|---|
| Abadan | 10.51 | 0.3 | 23.0 |
| Bandar Anzali | 0.88 | 1.1 | 33.2 |
| Esfahan | 0 | 18.9 | 44.0 |
| Bandar Abas | 39.44 | 0.0 | 15.0 |
| Babolsar | 1.81 | 1.4 | 31.8 |
| Zahedan | 0.01 | 14.0 | 45.0 |
| Tehran | 0.02 | 10.4 | 38.4 |
| Kermanshah | 0 | 23.6 | 47.1 |
| Tabriz | 0 | 26.6 | 47.1 |
| Mashhad | 0 | 23.0 | 44.4 |
| Shiraz | 0.01 | 10.1 | 42.1 |
| Yazd | 0 | 12.9 | 39.1 |

experience of cold stress, and Abadan experienced cold stress for only 0.3 % of the days of the year. The cities which experienced the least heat or cold stress, and thus the highest thermal acceptability were Kermanshah and Tabriz (both with acceptable thermal conditions for 47.1 % of days). The lowest thermal acceptability was for Bandar Abbas, at 15 % of days, resulting from the high thermal heat stress. Both heat stress and cold stress would be a significant deterrent for tourists.

*Heavy precipitation*

High-frequency heavy precipitation has a large impact on the tourism industry, both by deterring tourists, and through damage caused to infrastructure. There is no clear definition for heavy rain in Iran, so to determine a standard for heavy rain, official newspapers for the past 50 years were analysed for the number of rainy days which caused blocked water passages, floods or severe damage. From this a threshold of 15 mm in 24 h was determined indicative of heavy rain in Iran. This is however relative as for a station such as Yazd with an annual rainfall of 60 mm, a 24 precipitation with a value of 15 mm be very high, but for stations such as Bandar Anzali with annual rainfall of 2000 mm, a 24-h precipitation of 15 mm is not a considerable amount. As presented in Table 6, Bandar Anzali and Babolsar experienced the maximum number of days with heavy rainfall, at 37.9 and 20.1 days in a year, respectively. Both stations are located in the humid northern region of the country along the coast. The cities with the lowest frequency of days with heavy rainfall are Yazd and Zahedan, with averages of 0.64 and 0.96 days in a year, respectively, both of which are located in arid regions. For the majority of stations, the maximum frequency of heavy rainfall was in winter, presenting a deterrent for tourists in this season.

**Table 6**   Average frequency of days with heavy precipitation (more than 40 mm) for several months and selected stations in theperiod 1961 to2010

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | 0.9 | 0.4 | 0.4 | 0.3 | 0.02 | 0 | 0 | 0 | 0 | 0.1 | 0.5 | 0.7 | 3.32 |
| Bandar Anzali | 4.4 | 3.4 | 2.4 | 1 | 0.9 | 0.9 | 1 | 2.2 | 5.2 | 5.8 | 5.7 | 5 | 37.9 |
| Esfahan | 0.2 | 0.2 | 3 | 0.3 | 0.1 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.2 | 4.2 |
| Bandar Abas | 1 | 1.1 | 0.8 | 0.1 | 0.1 | 0 | 0.02 | 0.1 | 0.02 | 0.1 | 0.1 | 0.7 | 4.14 |
| Babolsar | 2.3 | 1.8 | 1.3 | 0.6 | 0.4 | 0.5 | 0.5 | 1.1 | 2 | 3 | 3.4 | 3.2 | 20.1 |
| Zahedan | 0.3 | 0.2 | 0.2 | 0.1 | 0 | 0 | 0.02 | 0 | 0 | 0.02 | 0.02 | 0.1 | 0.96 |
| Tehran | 0.5 | 4 | 0.6 | 0.4 | 0.1 | 0 | 0 | 0 | 0 | 0.2 | 0.3 | 0.7 | 6.8 |
| Kermanshah | 1.1 | 1.2 | 2.1 | 1.1 | 0.3 | 0 | 0 | 0 | 0 | 0.6 | 1.4 | 1.5 | 9.3 |
| Tabriz | 0.1 | 2 | 0.3 | 0.1 | 0.7 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 0.2 | 4.5 |
| Mashhad | 0.5 | 0.6 | 0.9 | 0.8 | 0.3 | 0.1 | 0 | 0 | 0.1 | 0.2 | 0.2 | 0.3 | 4 |
| Shiraz | 2.3 | 1.4 | 1.3 | 0.5 | 0.1 | 0 | 0.02 | 0.02 | 0 | 0.1 | 0.4 | 1.5 | 7.64 |
| Yazd | 0.02 | 0.1 | 0.2 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0.02 | 0.64 |

*Strong winds*

Strong winds are particularly problematic in Iran and would also provide a deterrent to tourists. Based on international standards and guidelines and codes of monitoring, Gale speed winds have speeds of over 34 knots. For Iran, the total frequency of occurrence winds exceeding these speeds for all selected stations is less than 0.1 % which reveals that Gale speed winds are rare phenomena in Iran. However, despite their low frequency in a year, they result in harmful damage. Bandar Abbas and Isfahan experience the maximum frequency of Gale speed winds, at 0.09 % of the observational period, followed by Tabriz with a frequency of 0.06 %. Cities with non-zero frequencies of Gale speed winds are Mashhad, Shiraz, Yazd and Babolsar (Table 7). For Babolsar and Bandar Anzali, the maximum frequency of severe winds occurred in autumn, whilst for Tehran and Abadan these winds occurred predominantly in spring. For all other stations, the highest frequency of Gale speed winds was in winter. Whilst winds of this severity are not very common, one storm could result in considerable damage and would pose a serious threat to the tourism industry if not mitigated for appropriately.

### Identification of peaks in annual tourism potential on the basis of climate in Iran

Scott and McBoyle (2001) argue that "theoretically the tourism climate resource of every location can be classified into one of six annual TCI distributions" (p. 74). These distributions include year-round optimal conditions, year-round poor conditions, summer peak conditions, winter peak conditions, dry season peak conditions and bimodal-shoulder peaks. The data from this study do not fall into the categories of year-round optimal, year-round poor or dry season peak for any of the stations across Iran. The summer peak distribution is observed for 50 % of the stations, where winter temperatures are too cold for tourism, but summer temperatures fall within

optimal thresholds. The bimodal-shoulder peak distribution is observed for a further 32.5 % of stations, where spring and autumn seasons are best suited to tourists as the conditions in summer and winter are too extreme.

A winter peak distribution is observed for 17.5 % of stations. These stations are predominantly located in lower latitudes, adjacent to the Persian Gulf and Oman Sea, where the cooler conditions and lower humidity than summer, favours tourism in this season. Examples of these distributions from the data in this study are presented in Fig. 4.

### Evaluation of the change points in TCI trends

The timing of the beginning of the trends in TCI value changes for each month are determined using the Mann-Kendall test, through analysing the intersection of the u(t) and u′(t) curves. For the majority of months, the change point was calculated to be in the 1970–1980s. This is consistent with the period of most rapid warming at a global scale (Walther et al. 2002). Notable exceptions are March and July where the change point was detected for the 1960s. The graphical representation of the Mann-Kendall test for change points is presented for only six stations in Fig. 5, whilst Table 8 reflects the change points for all stations.

### Future projections

To ensure that a climate model is suitable for a region, it is important to compare simulated climatic data for recent decades with the observational data for that period. Comparison of the observational data and the GCM output from 1980 to 2010 for the cities of Ardebil and Tehran demonstrates an acceptable agreement between modelled and true climate, and between the TCI scores derived from each of these datasets (Fig. 6). We can therefore use the data for the period 1961–2010 to project TCI scores for 2020–2040.

**Table 7** The start point of significant trends in TCI values observed for the period 1961–2010

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | | | | 1972 | | *** | *** | | | 1970 | | |
| Ahvaz | | 1972 | | | | | | | | | | |
| Anzali | | | | | | | | | | | 1977 | |
| Arak | | | | | *** | | | | | | | |
| Ardebil | | *** | *** | | *** | | | *** | *** | *** | *** | *** |
| Babolsar | | | | | | | | 1983 | *** | | | |
| Bam | | 1971 | 1969 | | | | | | | | *** | |
| Bandarabas | | 1998 | | | | | | 1985 | | 1971 | | |
| Bandarlenge | *** | 1978 | | | | 1967 | *** | *** | | | | |
| Birjand | | | | | | *** | *** | *** | | | | |
| Bushehr | | | | | | | | | | 1971 | 1971 | |
| Chabahar | | 1988 | | | | | | | | | 1986 | |
| Dezful | | 1966 | | 1983 | 1984 | | | 1967 | | | | |
| Esfahan | | 1984 | | | | | | | | | | |
| Fasa | | *** | | | *** | | | *** | *** | | | |
| Ghazvin | | | | | | | *** | 1970 | | 1970 | | |
| Gorgan | | | 1964 | | | | | *** | | 1980 | | |
| Hamedan | | | | | | | | | | | | |
| Iranshahr | | 1984 | 1984 | | | | | | | | *** | |
| Kashan | *** | 1984 | | | *** | *** | *** | *** | *** | *** | | |
| Kerman | | | | *** | | 1981 | | | | 1979 | *** | |
| Kermanshah | 1984 | | 1968 | 1972 | 1970 | | | | *** | | | |
| Khoramabad | | | | | *** | | | | *** | | | |
| Mashhad | | | | *** | | | | | | *** | | |
| Noshahr | 1970 | *** | | *** | *** | | *** | *** | | *** | | *** |
| Orumiyeh | *** | *** | *** | *** | | | | *** | *** | *** | *** | *** |
| Ramsar | | | | | | | | | 1983 | | | |
| Rasht | | | 1964 | | 1978 | | | | | 1985 | | |
| Sanandaj | 1984 | 1980 | | 1970 | | | | | | | | *** |
| Semnan | | | | | 1980 | | | | | | 1971 | 1980 |
| Shahrekord | 1976 | 1972 | | 1970 | | 1981 | 1965 | 1971 | 1979 | 1987 | | *** |
| Shahroud | 1970 | 1978 | | | | 1971 | | | | 1969 | | |
| Shiraz | | | | *** | | | | | | | | |
| Tabriz | 1968 | 1968 | *** | 1971 | | | | | | 1967 | 1973 | |
| Tehran | | | | | | | | | | 1967 | | |
| Torbat-e-Heidarieh | | | | | 1970 | 1971 | | *** | *** | *** | | |
| Yazd | | 1972 | 1969 | *** | | | | | | | *** | |
| Zabol | | | | | | | | | | | 1981 | |
| Zahedan | 1978 | | | *** | | 1970 | *** | *** | | 1987 | 1970 | |
| Zanjan | | | | | | *** | *** | | 1979 | | | |

***Months and stations with significant change but without start point of significant trend in TCI value

The output of the TCI scores calculated using projected climate variables for the years 2020–2040 is presented in Table 9 below. No significant change in the annual patterns of TCI scores, such as a change from a bimodal to summer peak has occurred. There have been changes in the direction and extent of the trends observed for the period 1960–2010, which are outlined in the sections below for each of the seasons. The relatively low incidence of deviation from the trends for the observational period are perhaps due to the short time interval between the observational period and the simulation which is required to produce accurate results. It is likely that as climate continue to change, there will be a critical threshold at

**Fig. 4** Annual distribution of climate tourism in some sample stations in Iran
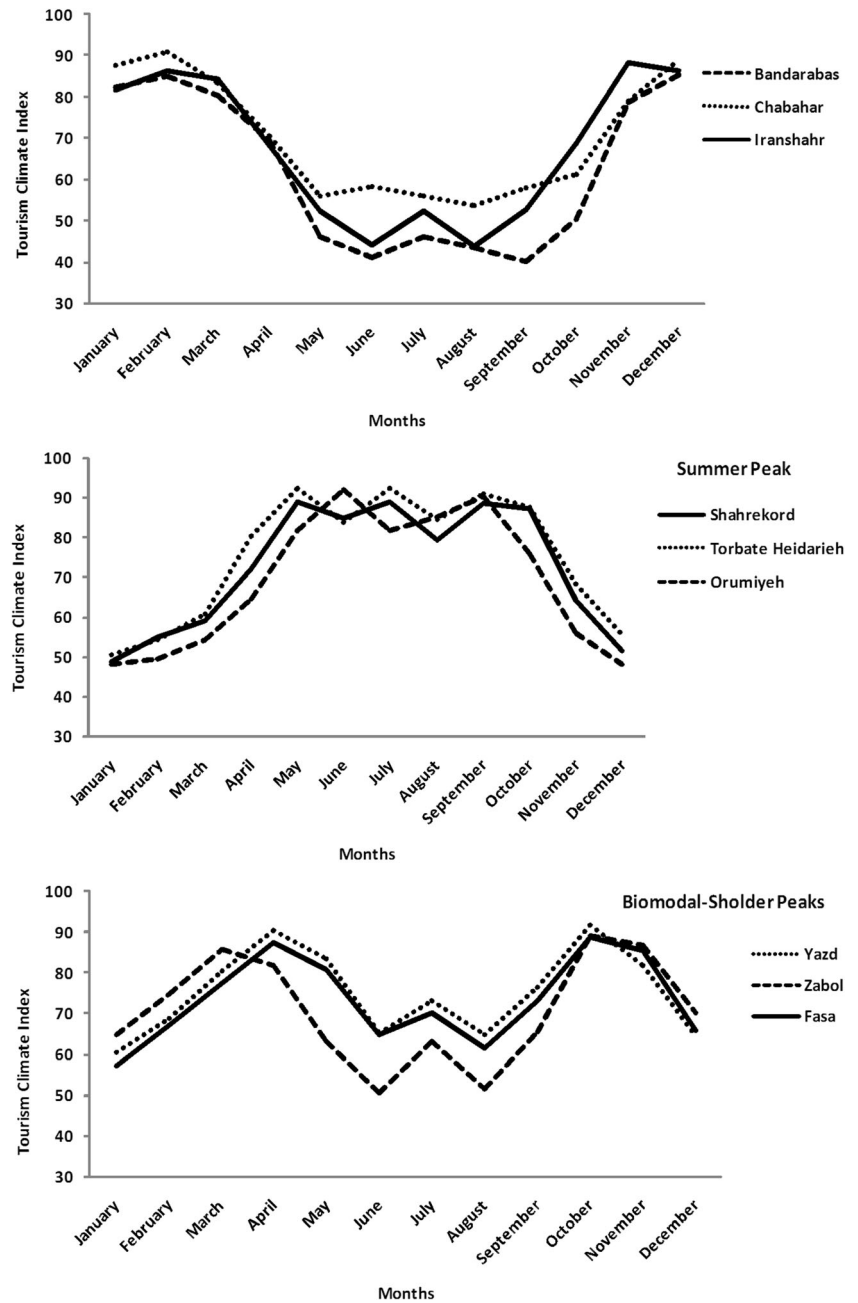
which temperatures become too high for comfort, resulting in a sudden shift from suitable to unsuitable TCI scores across a large number of stations. As these changes in trend direction are already occurring for some stations in the simulation period, adaptation measures should be implemented to mitigate for this in the second half of the twenty-first century.

Due to continued climate change, most of the stations across Iran demonstrate improved climatic conditions for tourism in winter than in past decades (Fig. 7). These improved conditions are most noticeable for cities in the west and northwest, including Kurdistan, Kermanshah, Urumieh, Tabriz and Ardebil. The improvement is least significant for cities located in the southern coastal region, including Bandar Abbas Bandar Lengeh, Bushehr and Abadan. A decrease in TCI scores is observed for the northern cities of Iran, including Anzali, Rasht and Babolsar. Projections for these cities suggest increased precipitation, resulting in a decrease in sunshine hours which negatively affects the TCI scores.

For spring, an increase in TCI scores from the observational to the simulated period is projected for cities in the west, northwest and north-east of the country (Fig. 7). Cities in the southeast of Iran and along the shores of the Persian Gulf would experience a decrease in scores. The cities to the north along the Caspian coast demonstrate no significant change. For some stations, such as Kashan and Fasa, the change in

**Fig. 5** Graphical representation of sequential values of the statistics forward series u(t) (*solid line*) and backward series U′(t) (*dashed line*) obtained by SQ-MK test for monthly TCI series at some stations with the significant trends
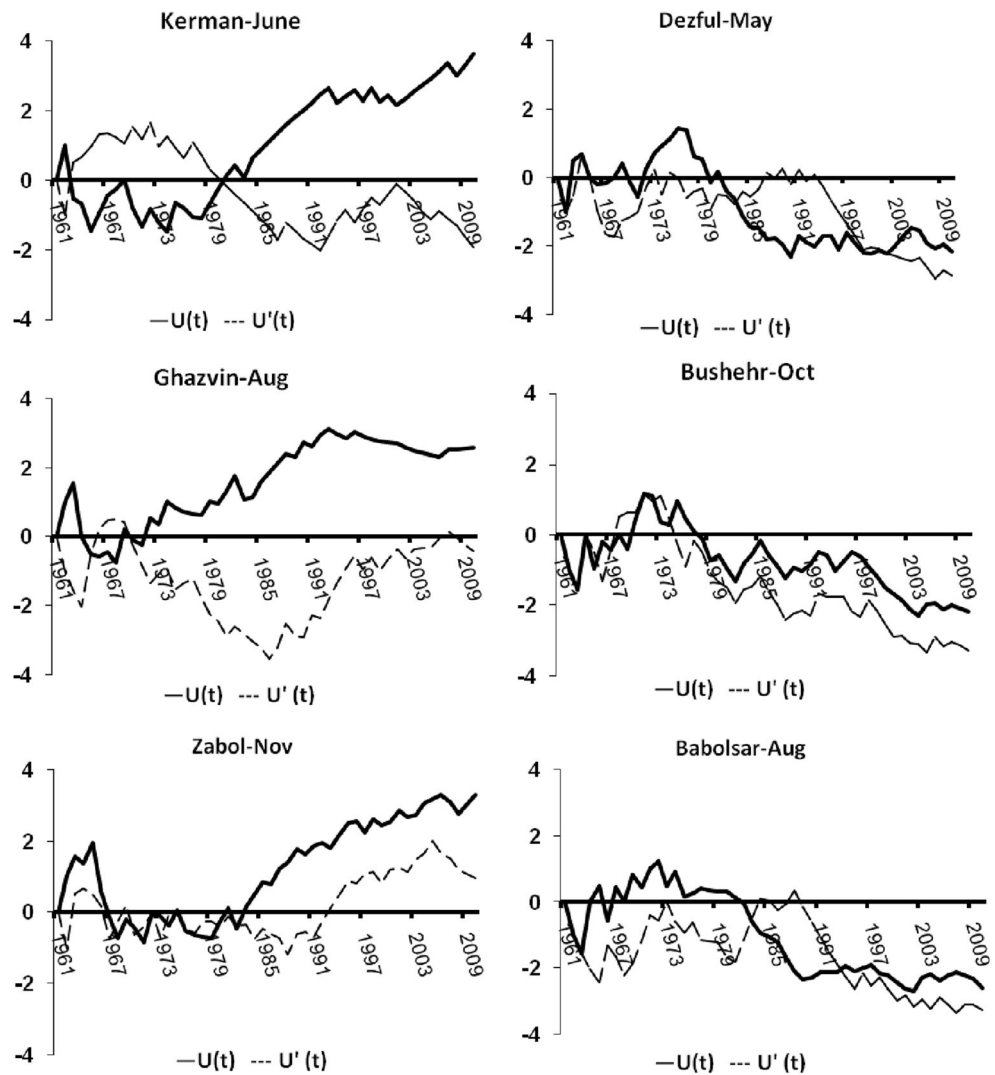


TCI score results from projected shifts in the timing of rainfall to spring, whereas for other cities changes are driven predominantly by changes in temperature.

For summer, a significant decrease in TCI scores is projected for the majority of cities, with the most extreme change for cities on the south coast (Fig. 7). These decreases in TCI score result

**Table 8** Total and monthly frequency of hours of severe winds for stations in Iran for the observational period of 1961 to 2010

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | 2 | 10.2 | 6.1 | 4 | 28.6 | 20.4 | 8.4 | 14.3 | 2 | 0 | 0 | 4 |
| Bandar Anzali | 14.7 | 13.1 | 4 | 1 | 1 | 3.3 | 2.5 | 0.8 | 10.7 | 23.6 | 17.9 | 7.4 |
| Esfahan | 7.8 | 18.6 | 22.8 | 25 | 15 | 2.8 | 0 | 0 | 1.4 | 0 | 2.3 | 4.3 |
| Bandar Abas | 23 | 23 | 3.8 | 3.8 | 0 | 3.8 | 0 | 0 | 0 | 0 | 15.6 | 27 |
| Babolsar | 16.6 | 11.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16.6 | 44.4 | 11.3 |
| Zahedan | 16.2 | 23.9 | 25.3 | 16.6 | 2.4 | 1.4 | 1.7 | 0.3 | 0 | 0.3 | 0.3 | 11.6 |
| Tehran | 2.1 | 6.4 | 4.2 | 27.8 | 38.3 | 6.4 | 2.1 | 2.1 | 0 | 4.2 | 6.4 | 0 |
| Kermanshah | 10 | 14.3 | 18.6 | 20 | 12.9 | 2.9 | 1.4 | 2.8 | 0 | 7.1 | 4.3 | 5.7 |
| Tabriz | 11.2 | 3.6 | 16.2 | 14.4 | 10 | 5.5 | 11 | 5.5 | 2.7 | 14.4 | 4.5 | 1 |
| Mashhad | 11.1 | 44.5 | 0 | 11.1 | 0 | 0 | 0 | 0 | 0 | 11.1 | 22.2 | 0 |
| Shiraz | 0 | 7.1 | 35.8 | 35.8 | 0 | 7.1 | 0 | 0 | 0 | 7.1 | 0 | 7.1 |
| Yazd | 10 | 21.6 | 15 | 20 | 16.6 | 5 | 0 | 0 | 3.4 | 3.4 | 0 | 5 |

**Fig. 6** Validation of the annual cycle of TCI values based on simulated data and experimental data for the observational periods of 1980 and 2010
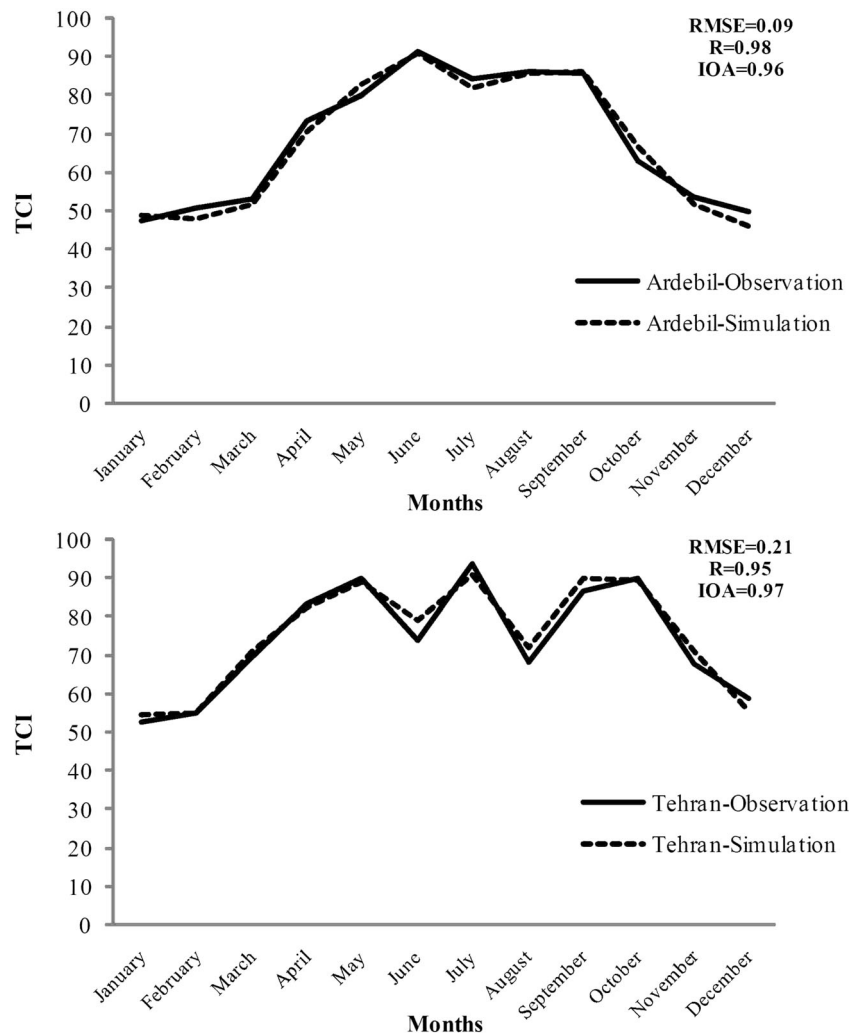


from an increase in summer rainfall and humidity, together with temperature increases past the threshold for acceptable conditions. Changes in rainfall are the largest driver of TCI score change for cities in the south, whilst changes in temperature and humidity are more dominant in the north of the country.

By contrast to summer, an increase in TCI scores is observed for the majority of cities in autumn (Fig. 7). This is as a result of a significant decline in rainfall projected for the period 2020–2040 driven by changes in the Siberian high pressure cell, whilst the associated increase in temperature shifts thermal conditions into a more acceptable range. The increases in TCI score are most significant for cities in the west and northwest of Iran and along the Caspian coast in the north. The smallest change in TCI scores is observed for the southern region of the country.

## Discussion

The aim of this study was to identify the effect of climate change on the TCI for various stations across Iran. Analyses of the long-term average TCI values indicate fluctuations between months

from the marginal to ideal category. In most months, based on total average of TCI index for 40 studied stations, the TCI for Iran is categorised as good to very good. Determining the role which climate change has played on the TCI for the 40 stations across Iran, trends for the period 1961–2010 were investigated. For all months of the year, trends towards increasing TCI values are observed for at least one station, and for the months of March, June and July no significant decreasing trends are observed. For the month of October, 45 % of stations demonstrated significant increasing trends in TCI values, providing a promising outlook for continued tourism in this month across Iran. December observed the least change in TCI values over the study period. The most rapid changes in TCI values are observed for May, at 3.51 TCI units per decade. The majority of these trends in TCI values are calculated to have started in the 1970s and 1980s. This may be a result of factors such as changes of station locations, changes in data recording devices and devices for measuring meteorological data, the time of measurement of climatic parameters or the atmospheric circulation and is furthermore consistent with the period of intense climate warming.

**Table 9** Long-term average TCI values for each of the climate stations for the period 2020–2040

| Stations | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadan | 69 | 83 | 87 | 75 | 51 | 36 | 50 | 37 | 39.5 | 52.3 | 81 | 73 |
| Ahvaz | 65 | 80.4 | 86 | 71 | 50 | 40 | 52 | 41 | 41 | 57.1 | 82.7 | 70.2 |
| Anzali | 45 | 41 | 41.5 | 59 | 79 | 78 | 85.5 | 49 | 60 | 61.3 | 55 | 43 |
| Arak | 47 | 54 | 59 | 77 | 93 | 85 | 85.2 | 71 | 82.6 | 84 | 65 | 55 |
| Ardebil | 39 | 55 | 58 | 74 | 81 | 90 | 85 | 88 | 85 | 71 | 55 | 42 |
| Babolsar | 48.8 | 50 | 47 | 68 | 88 | 76 | 89 | 45 | 57.7 | 73 | 64 | 52.2 |
| Bam | 72 | 85 | 86 | 91 | 66.5 | 45 | 66 | 43 | 67 | 88 | 92 | 78 |
| Bandarabas | 82 | 87 | 79 | 61 | 42.5 | 37.5 | 45 | 39 | 39.5 | 49 | 77 | 85 |
| Bandarlenge | 85 | 88.2 | 83.1 | 68 | 50 | 40.7 | 52 | 42 | 36 | 55 | 81 | 83.9 |
| Birjand | 55 | 47 | 73 | 86 | 90 | 85 | 93 | 69 | 85 | 92 | 86 | 60 |
| Bushehr | 69 | 77 | 87 | 81.5 | 55 | 47 | 49 | 37 | 35 | 55 | 83 | 75.5 |
| Chabahar | 82 | 92.5 | 85 | 69 | 57.7 | 58 | 49.1 | 49 | 55 | 57 | 78.8 | 88 |
| Dezful | 63 | 75 | 83 | 80 | 66 | 45 | 52 | 37 | 49 | 67 | 82 | 61 |
| Esfahan | 55 | 60.1 | 73 | 93 | 96 | 80 | 95 | 64.6 | 85 | 92 | 76.2 | 56 |
| Fasa | 55 | 66 | 80 | 90 | 76 | 64 | 66 | 60 | 65 | 90.3 | 88 | 69.2 |
| Ghazvin | 53 | 52 | 59 | 85 | 89 | 88 | 94 | 78 | 85 | 89 | 66 | 43 |
| Gorgan | 58 | 57 | 63 | 77 | 75 | 64 | 80 | 47 | 55 | 76 | 73 | 55 |
| Hamedan | 37 | 55 | 57 | 74 | 87 | 93 | 84 | 75 | 92 | 87 | 59 | 43 |
| Iranshahr | 84 | 88.7 | 84 | 65 | 53.5 | 45 | 50 | 37 | 48 | 60.3 | 91 | 90 |
| Kashan | 60 | 60.1 | 69 | 82 | 71 | 57 | 82 | 60.4 | 68 | 89 | 83 | 60 |
| Kerman | 57 | 73 | 78 | 96 | 94.8 | 80.2 | 92 | 71.2 | 88 | 82 | 83 | 67 |
| Kermanshah | 36 | 55 | 62 | 85 | 84 | 80 | 90 | 67 | 83 | 89.2 | 65.5 | 41.7 |
| Khoramabad | 44 | 52 | 67 | 85 | 80 | 63 | 87 | 59 | 66 | 87 | 66 | 57 |
| Mashhad | 46.6 | 54 | 55 | 80 | 90 | 82 | 90 | 80 | 90 | 83 | 69 | 55 |
| Noshahr | 46.5 | 49 | 51 | 63 | 83.3 | 76 | 80 | 47 | 59.3 | 65 | 52 | 67.1 |
| Orumiyeh | 42.3 | 47 | 59.5 | 74 | 80 | 92 | 87 | 87 | 88 | 85 | 57 | 42.2 |
| Ramsar | 46.5 | 46.5 | 43 | 58.9 | 78 | 74 | 79 | 57 | 55 | 67 | 55 | 51.5 |
| Rasht | 43.3 | 45 | 47 | 65 | 81 | 69 | 65 | 42 | 51 | 65 | 52.8 | 47 |
| Sanandaj | 43 | 57 | 50 | 78 | 87 | 89 | 89 | 70 | 92 | 81 | 57 | 43.2 |
| Semnan | 62 | 60 | 66 | 81 | 78 | 73 | 89 | 61 | 86 | 92 | 64 | 64.2 |
| Shahrekord | 47 | 52 | 49 | 75 | 88 | 85 | 95 | 84 | 91 | 95.3 | 66 | 51 |
| Shahroud | 50 | 48 | 57 | 83 | 91 | 87 | 90 | 88 | 95 | 90 | 69 | 57.7 |
| Shiraz | 57 | 67 | 70 | 88 | 92 | 78 | 89 | 62.3 | 71 | 90 | 85.8 | 53 |
| Tabriz | 37 | 55 | 59 | 60 | 89 | 93 | 85 | 83 | 96 | 87 | 63 | 45 |
| Tehran | 55 | 56 | 57 | 79 | 90 | 82 | 97 | 56 | 83 | 90 | 68 | 57 |
| Torbat-e-Heidarieh | 44 | 56 | 53 | 82.7 | 92.7 | 87 | 95 | 88 | 88.4 | 88 | 66 | 59 |
| Yazd | 59 | 66 | 83.3 | 94 | 87 | 70 | 72 | 57 | 69.6 | 92 | 84 | 59.3 |
| Zabol | 65 | 77 | 84 | 83 | 66 | 50 | 62.5 | 49.3 | 67 | 88 | 85 | 71 |
| Zahedan | 69.4 | 73 | 87 | 93 | 81.5 | 69 | 81.2 | 66.4 | 82.2 | 92 | 88 | 69.9 |
| Zanjan | 46 | 45 | 61 | 65 | 87 | 95.2 | 87 | 90 | 93 | 77 | 59 | 40 |

Despite numerous studies determining the TCIs for regions in Iran, no research has explored changes in TCI trends over time in order to validate the output of current values. Studies have investigated changes in one or more of the climate variables included in the TCIs in isolation, which serve to confirm many of the patterns observed in this study. The role of precipitation changes in the comfort indices and TCIs is of interest due to the projected increase in rainfall variability globally. In particular, the percentage of total annual precipitation and rainy days has significantly decreased for north, west and north-east of Iran over the last six decades (Rahimzadeh et al. 2009; Raziei et al. 2014). Notable is that these decreases in precipitation have resulted in improved TCI values calculated in this study, due to rainfall being perceived
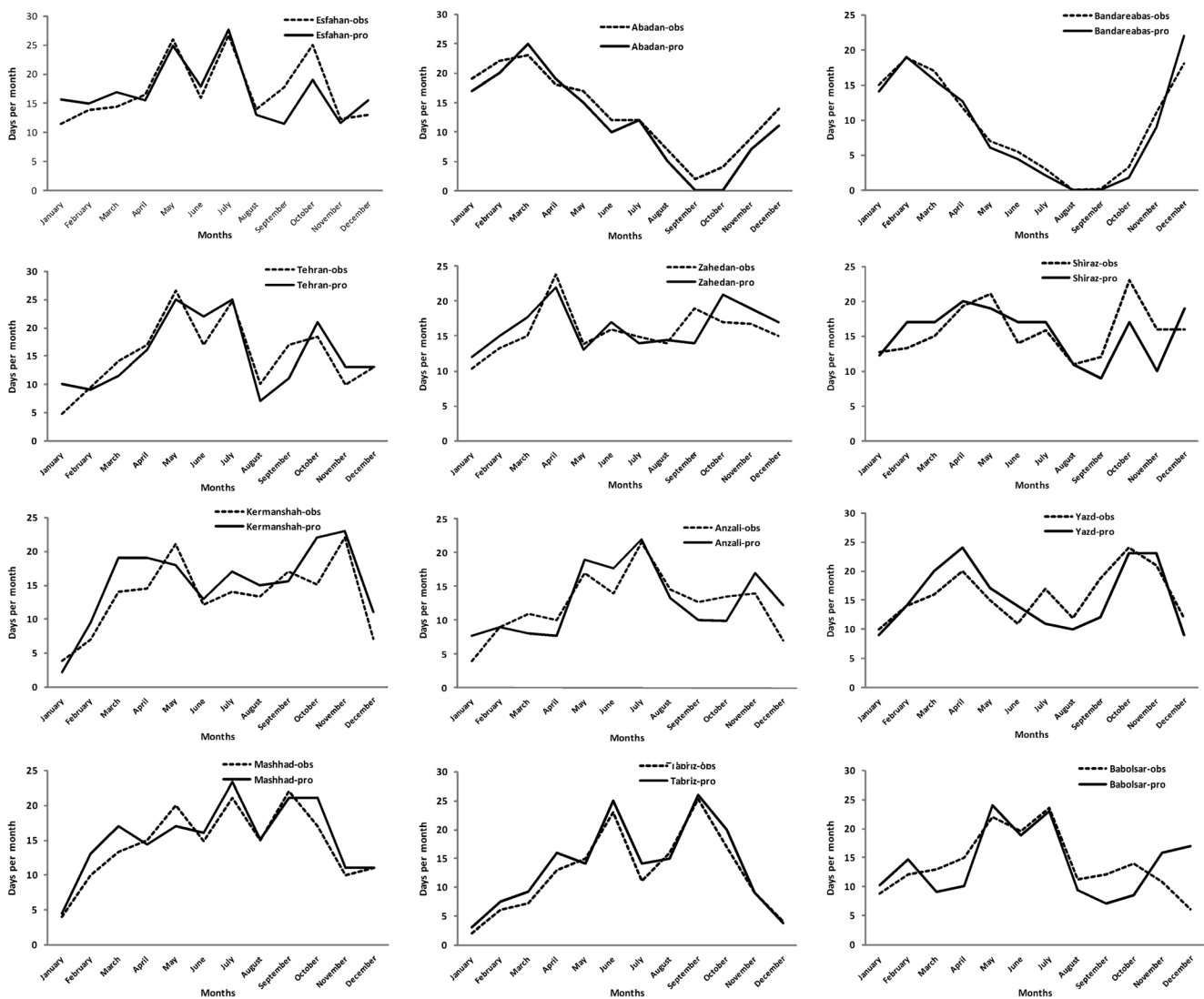
Fig. 7 Comparison of the average of TCI scores for observational period (1960–2010) and future period (2020–2040) for a selection of stations

as a deterrent to tourists, despite the potential for water short-ages. Simultaneous with decreases in precipitation, analyses of sunshine hours across Iran for the period 1981–2007 found increasing trends for 94.6 % of stations (Rahimzadeh et al. 2014), which further improve the TCI values. Analyses of trends in extreme climate conditions found decreases in the diurnal temperature range, frost days, ice days, cool days and cool nights for the majority of stations across Iran (Rahimzadeh et al. 2009). For the arid to semi-arid regions of Iran, winter temperatures have been found to have in-creased (Tabari and Talaee 2011a). These trends in climate variables which are included in the TCIs serve to confirm the TCI findings in this study for the 50 stations across Iran.

Studies have been conducted on changes of climate com-fort indices, which provide comparison with the results of this study. A study for the city of Shiraz found changes in bioclimatic trends in response to climate change, which have result-ed in more favourable conditions for cold seasons of the year,

and consistent with our results, demonstrate most favourable conditions in this city for the month of May (Shakoor et al. 2008). A study of the city of Anzali on the southern coast of the Caspian Sea, which analysed effective temperature, found that climates which best suited the comfort index were expe-rienced in spring and summer, which again is consistent with the findings of this study (Ramezani et al. 2013). Using an index of physiologically equivalent temperature for Urumieh Lake in northwest Iran, the most favourable climate was iden-tified for the months of June to September (Farajzadeh and Matzarakis 2012). Adjacent cities included in our study, Ta-briz and Urmia, found favourable conditions for tourism across these same months. A study on averaged TCIs for Kerman Province in southeast Iran found bimodal-shoulder peaks for the cities of Kerman and Bam, again consistent with the findings in this study.

The majority of stations demonstrated trends of improving TCI values over the period 1961–2010, due to climate

changes which moderate the temperature, increase sunshine hours, and reduce humidity and precipitation. The majority of the stations for which TCI values have improved, have a typically colder climate, which is ameliorating under warming conditions, and providing more suitable conditions to tourists, particularly in the colder seasons (Rahimzadeh et al. 2009; Tabari and Hosseinzadeh Talaee 2011a, b; Zarenistanak et al. 2014). For the stations of Kashan and Iranshahr which have typically experienced hot and dry climate, decreases in temperature and increases in precipitation have been advantageous. The significant number of stations for which the TCI values are increasing provides a positive outlook for sustainable tourism potential in the country. Caution must be taken by decision-makers to ensure that the geographic patterns of these regions of improvement are understood, and that the development of tourism infrastructure be prioritised for these cities in which increasing TCIs are reported. Furthermore, the critical thresholds of each of these climate variables must be considered in order to make provision for long-term climate adaptation in these regions, should tourism be prioritised.

A few of the stations, including Abadan, Bushehr, Fasa, Dezful, Zabol, Tehran and Babolsar, have experienced a decreasing trend for TCI over the period 1961–2010. For Fasa, Dezful and Zabol, this is most strongly driven by the increase in temperatures, consistent with the increase in global temperature, which is felt particularly severely in these already hot, arid locations. The capital city of Tehran has additional heat stresses from the urban heat island, which has worsened over recent decades due to urban sprawl (Roshan et al. 2009; Roshan et al. 2010). The cities of stations of Bushehr, Abadan and Babolsar are located in coastal regions, which have experienced increased humidity together with temperature increases, resulting in a decrease in the TCI from three variables (Roshan et al. 2010). Finally, for the city of Babolsar, the increase in cloud cover and precipitation has been the most significant drivers in the decrease in TCI (Nazemosadat et al. 2006; Rahimzadeh et al. 2009).

Looking forward, it is important to note that changes in the direction of the TCI trends are already occurring and that many locations are projected to see decreases in TCI scores by 2020–2040 for at least one season. These decreases are driven predominantly by projections of increasing precipitation and in shifts of the onset of precipitation. Further decreases result from temperature increases which during recent decades have improved the climate for tourism, but with continued increases in future exceed the threshold for comfort levels. At a regional scale, cities in western and northwestern Iran are projected to experience favourable climate for tourism from mid-spring to early autumn. For the northern coast, the ideal period for tourism will be restricted to autumn. For the southern region, tourism suitability is projected to decrease for the majority of the year, but the temperature increases in winter will make this currently unsuitable season the only time of

the year suitable for tourism. It is important that tourism initiatives be made aware not only of both the inclement climate conditions at present in these locations but also of the long-term decreasing trends in TCI values so as not to invest in tourism infrastructure in locations that are likely to become climatically unsuitable (Matzarakis et al. 2014).

## Conclusions

Tourism is one of the largest and fastest growing international sectors. The Iranian economy remains highly dependent on oil export revenue, which places the country at extreme financial risk due to fluctuations in oil prices, the non-renewable nature of the asset and the global shift to cleaner technology. In order to diversify the sources of economic growth, foreign exchange and various dimensions of job opportunities in the country, tourism development is of great importance. A deliberate economic shift to include tourism would require that regions of sustainable tourism be identified and favoured to ensure consistent long-term growth and return on investment. TCI results for the majority of stations across Iran confirm that the climate conditions are already suitable for tourism in many locations, and long-term trends indicate improved conditions for tourism across the majority of stations. The TCIs further identify the most suited seasons for tourism in each of the cities, with the majority demonstrating most favourable conditions for spring and summer, whilst winter peaks and bimodal peaks are observed for a couple of cities. Understanding the current TCI-based suitability of each city, the trends in TCI values over the period 1961–2010 and the months and seasons for which TCI values are highest for each city would facilitate improved planning and decision making for the development of tourism infrastructure in Iran, and the promotion of long-term sustainable tourist destinations.

The results reveal that, overall, the seasons of spring through summer offer the best climate conditions for tourists (with an average TCI index of 74.6), whilst winter are the least favourable, with a TCI score of 61.3. In winter, the cities located on the coast of the Persian Gulf and Oman Sea have the best climate conditions for tourism, due to warm temperatures, clear skies and rare occurrence of precipitation. Cities on the coast of the Caspian Sea have the least favourable conditions, due to high rainfall volumes, low sunshine hours and temperatures outside of comfort levels. The study confirms that the TCI output for Iran can be classified into three distributions: summer peak accounting for 50 % of stations, bimodal-shoulder peak accounting for 32.5 % of stations and winter peak accounting for 17.5 % of stations. The results of this study contribute to the potential for management and adaptation strategies to introduce tourism as a sustainable economic sector in Iran, despite changing climate conditions. The

results further contribute to increasing academic literature on TCIs globally.

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