



Influence of non-stationarity and auto-correlation of climatic records on spatio-temporal trend and seasonality analysis in a region with prevailing arid and semi-arid climate, Iran

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Abstract: Trend and stationarity analysis of climatic variables are essential for understanding climate variability and provide useful information about the vulnerability and future changes, especially in arid and semi-arid regions. In this study, various climatic zones of Iran were investigated to assess the relationship between the trend and the stationarity of the climatic variables. The Mann-Kendall test was considered to identify the trend, while the trend free pre-whitening approach was applied for eliminating serial correlation from the time-series. Meanwhile, time series stationarity was tested by Dickey-Fuller and Kwiatkowski-Phillips-Schmidt-Shin tests. The results indicated an increasing trend for mean air temperature series at most of the stations over various climatic zones, however, after eliminating the serial correlation factor, this increasing trend changes to an insignificant decreasing trend at a 95% confidence level. The seasonal mean air temperature trend suggested a significant increase in the majority of the stations. The mean air temperature increased more in northwest towards central parts of Iran that mostly located in arid and semi-arid climatic zones. Precipitation trend reveals an insignificant downward trend in most of the series over various climatic zones; furthermore, most of the stations follow a decreasing trend for seasonal precipitation. Furthermore, spatial patterns of trend and seasonality of precipitation and mean air temperature showed that the northwest parts of Iran and margin areas of the Caspian Sea are more vulnerable to the changing climate with respect to the precipitation shortfalls and warming. Stationarity analysis indicated that the stationarity of climatic series influences on their trend; so that, the series which have significant trends are not static. The findings of this investigation can help planners and policy-makers in various fields related to climatic issues, implementing better management and planning strategies to adapt to climate change and variability over Iran.

Keywords: climate change; trend analysis; stationarity tests; serial correlation; seasonality; arid and semi-arid regions

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1 Introduction

Water resources decision makers require analysis tools to develop the appropriate strategies for efficient water resources management under changing climate (Sahoo and Smith, 2009; Duan et

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al., 2019). Analyzing the trend and stationarity of climatic variables provides information on understanding climate change and future possibilities (Unal et al., 2012; Zhou et al., 2015; Libanda et al., 2019). The methods for detecting the trend of meteorological series are mainly categorized into parametric and non-parametric methods (Zhang et al., 2006). Compared to the parametric trend tests, the non-parametric ones are more appropriate for naturally observed meteorological time series (Hamed, 2009; Shadmani et al., 2012). The Mann-Kendall (M-K) test (Mann, 1945; Kendall, 1975) is one of the most popular non-parametric methods utilized for testing the trend of natural series. Many researchers have used the M-K test in different research fields including climatological and hydrological studies (Xu et al., 2003; Zhao et al., 2015; Zhou et al., 2015; Duan et al., 2017). Most of these studies have proven the M-K test as an effective and robust technique for identifying the monotonic trend of natural time series. The M-K test is efficient even if there is a seasonal component in the time series (Hirsch et al., 1982), but it is not robust against the serial correlation of the series which would affect the statistics of the test (Shao and Li, 2011); therefore, different alternatives have been suggested to eliminate the effects of time series auto-correlation (Burn and Elnur, 2002; Aziz and Burn, 2006). Among the various approaches of removing time series auto-correlation, the trend free pre-whitening (TFPW) is an effective approach to remove the first order auto-regression (AR(1)) component. Time series de-trending prior to pre-whitening provides a more accurate estimation of AR(1) compared to the other pre-whitening approaches in serially dependent series. Numerous researchers have used auto-correlation approaches for trend detection in natural time series (Yue and Wang, 2002; Yue et al., 2002; Some'e et al., 2012; Feizi et al., 2014; Ahmad et al., 2015; Toller et al., 2019). Non-stationarity is a common term in climatic and hydrological time series that is in close proximity to the trend. Stationarity in climatic variables means that they fluctuate within an unchanging cover of variability, randomly (Wu et al., 2007); therefore; non-stationarity is a sign of a gradual trend or a sudden shift (Wang et al., 2005). There are few cases which have studied the non-stationarity of climatic series and its effects on climatic series trends both in the world and Iran (Wang et al., 2005; Wu et al., 2007; Sun et al., 2018; Um et al., 2018; Parey et al., 2019). As stationarity and trend identification in climatic records provide ideas about better water resources management, it must be considered in climatic modelling investigations.

Iran's natural ecosystem and resources are very vulnerable to the climate variability and change since it is located mostly in the arid and semi-arid regions. A number of researchers have studied the trend of climatic time series in Iran, using different trend detection techniques (Raziei et al., 2005a; Tabari et al., 2011; Some'e et al., 2012; Delju et al., 2013; Feizi et al., 2014; Hosseinzadeh, 2014; Fathian et al., 2015). Delju et al. (2013) argued that the mean precipitation amounts decreased by about 9.2% in Urmia Lake Basin in northwestern Iran from 1964 to 2005. Using the M-K test and datasets from 1967 to 2006, Some'e et al. (2012) demonstrated a downward trend for annual precipitation series in 79% of the stations; furthermore, the results showed a significant reduction in precipitation over the northern Iran. Tabari et al. (2011) assessed the trend of annual precipitation over the western, southern and south-western Iran from 1966 to 2005. They identified that there was no significant trend in the series over this period. In recent years, the frequency and persistence of dry periods have significantly increased over various climatic zones in Iran (Abbaspour and Sabetraftar, 2005; Amiri and Eslamian, 2010; Golian et al., 2015). A high population growth rate in some parts of Iran also in association with adopting inappropriate water management strategies, especially in central arid zones, has caused high pressure on water resources, especially groundwater resources in these areas; so, identifying the trends of the observed climatic series can lead to a better understanding of potential tendency in future and consequently, adopting more effective water management strategies under a changing climate.

The purposes of this research are (1) to characterize the precipitation and mean air temperature trends and seasonality over various climatic zones of Iran before and after applying a pre-whitening approach to demonstrate the effect of serial correlation of the climatic series on their trends; and (2) to analyze the influence of climatic series stationarity on their trend and seasonality. Analyzing the stationarity of climatic records is one of the most important stages before modelling any hydrological system since it can happen as a gradual trend and also a sign of climate change

(Brockwell and Davis, 1991). Conducting this phase before any climatic and hydrological modelling could allow the researchers to achieve more accurate results and consequently adopt more efficient decisions on climate-related issues.

2 Materials and methods

2.1 Study area and datasets

Iran is a high plateau (24°–40°N, 44°–64°E) located in arid and semi-arid regions of the Earth. Climatically, most parts of Iran are classified as arid and semi-arid (Peel et al., 2007). About 30% of the precipitation occur in the form of snow and the rest is in rainfall and other forms. Precipitation vary both temporally and spatially. Some regions in the south of the Caspian Sea receive more than 2000 mm of annual precipitation while annual precipitation is less than 50 mm in the central and eastern Iran. Most of precipitation occur during autumn and winter because of the association of precipitation with western Mediterranean winds (Alijani, 1995). Due to the high climate variability, as well as the effects of changes in climate variables on other systems, it is vital to study and analyze the trend and stationarity of climatic series based on various climatic zones. Figure 1 shows the geographical location of the study region in association with the stations in various climatic zones over Iran based on the De-Martion climate classification index (Table 1).

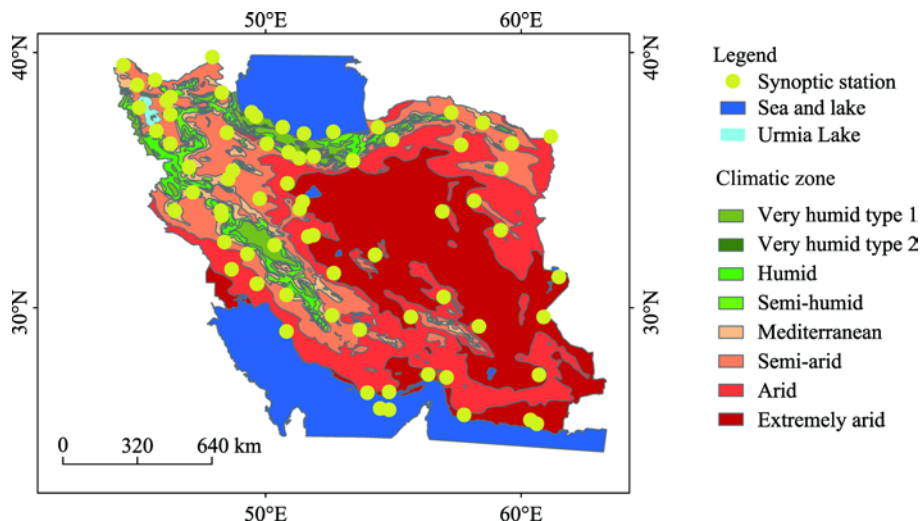


Fig. 1 Location of the synoptic stations in different climatic zones of Iran

Table 1 De-Martion drought coefficient range

Climatic zone	Drought coefficient	Number of stations selected
Very humid type 1	>55.0	4
Very humid type 2	35.0–54.9	1
Humid	28.0–34.9	1
Semi-humid	24.0–27.9	0
Mediterranean	20.0–23.9	6
Semi-arid	10.0–19.9	27
Arid	5.0–9.9	16
Extremely arid	<4.9	18

Detecting variability of climatic records requires reliable and integrated time series. In this study, the time series of monthly precipitation and mean monthly air temperature, measured in 73 synoptic stations (1985–2014) over Iran, were selected to determine the trend, seasonality and stationarity of the climatic series. The nearest neighbor approach was used for rebuilding the missing data. The

randomness and the independence of the series were examined by the runs test and the non-parametric Mann-Whitney test, respectively (Fig. 2). The characteristics of the selected stations were summarized (Table S1).

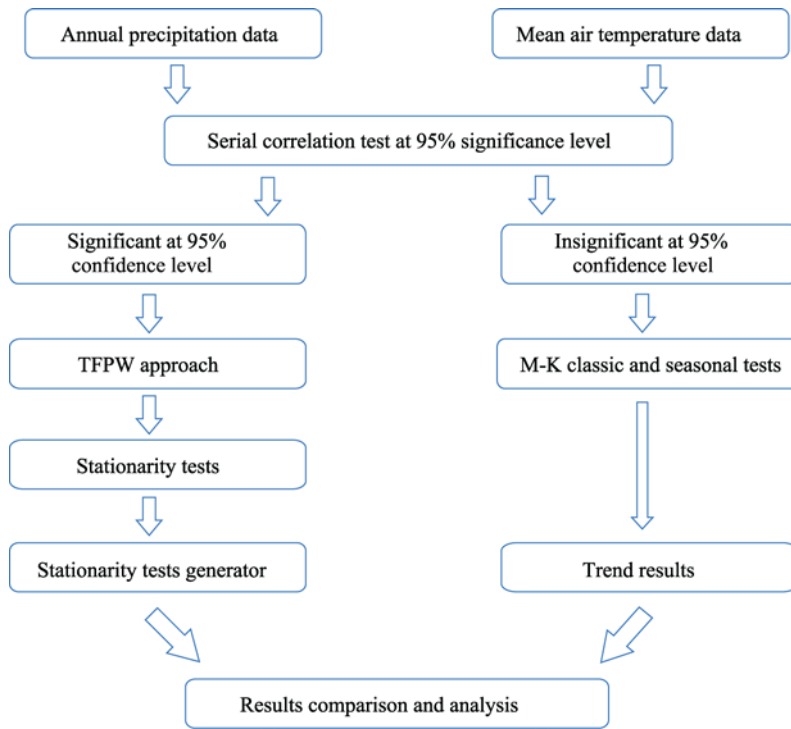


Fig. 2 Procedures and steps of the study

2.2 Trend and seasonality detection

The classic M-K test is a non-parametric approach that is utilized in different types of time series to identify the monotonic trend of the records. This test is firstly proposed by Mann (1945) and further developed by Kendall (1975) and finally improved by Hirsch et al. (1991, 1982), who allowed the method to take into account the seasonality. The null hypothesis (H_0) indicates that the series belongs to an independent population which is identically distributed; otherwise, the alternative hypothesis (H_a) shows that the records follow a monotonic trend. The M-K tests are based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks with the samples. The computations assume that the observations are independent (Hosseinzadeh, 2014; Blain, 2015).

In this method, the differences between each observation with all subsequent observations are calculated (Eq. 1).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k), \quad (1)$$

where S is the number of positive differences minus the number of negative differences; n is the number of data in the time series; and x_j and x_k are the j^{th} and k^{th} data of series, respectively. The sgn function is calculated as Equation 2.

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases}. \quad (2)$$

In the next step, the calculation of the variance S is carried out by one of the Equations 3 and 4, which depends on the number of data in the time series.

$$\text{Var}(S) = \begin{cases} \frac{n(n-1)(2n+5) - \sum_{i=1}^m t(t-1)(2t+5)}{18} & \text{if } n > 10 \\ \frac{n(n-1)(2n+5)}{18} & \text{if } n < 10 \end{cases}, \quad (3)$$

where n and m are the numbers of sequences in which there is at least one duplicate data; t indicates the frequency of the values of the same value in a sequence (number of nodes).

Z is the statistic obtained from Equation 4,

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}. \quad (4)$$

Assuming that the trend test is two-tailed, the null hypothesis is accepted if,

$$|Z| < Z_{\alpha/2}, \quad (5)$$

where α is the significance level that is considered for testing; and $Z_{\alpha/2}$ is the standard normal distribution statistic at α significance level.

The seasonal M-K statistics (S_g) is defined as:

$$S_g = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_{jg} - x_{ig}) \quad g = 1, 2, \dots, m. \quad (6)$$

The seasonal M-K statistics for the entire records (\hat{S}) is calculated as:

$$\hat{S} = \sum_{g=1}^m S_g. \quad (7)$$

More details about seasonal M-K descriptions and equations can be found in Hirsch et al. (1991).

2.3 Auto-correlation modification

The existence of serial correlation could make trend identification too complex which may result in false outcomes for M-K test (Burn et al., 2004). There are several techniques to eliminate serial correlation from a series that the pre-whitening approach is more common among them, although investigators (Yue et al., 2002; Blain, 2015) indicated that pre-whitening can eliminate some of the trends as removing serial correlation; therefore, another approach calling the TFPW was developed. In this study, the following steps are applied before conducting the M-K test:

Firstly, removing linear trend from the raw time series using Equation 8.

$$Y_t = X_t - \beta_t, \quad (8)$$

where X_t , β_t and Y_t are the series value, linear regression slope of the trend in the raw time series and de-trended series at time t , respectively.

Secondly, removing serial correlation if the lag-1 serial correlation coefficient of the de-trended series is statistically significant at 5% confidence level:

$$Y'_t = Y_t - r_1 Y_{t-1}, \quad (9)$$

where Y'_t is the de-trended and pre-whitened series that is referred to as the residual series.

Thirdly, adding the linear trend that was removed at step 1 back to the de-trended or residual series by,

$$Y''_t = Y'_t - \beta_t, \quad (10)$$

where Y''_t is the trend-free pre-whitened series.

2.4 Stationarity analysis

If the statistical features of a time series do not vary with time, it is considered as a statistic time series. Stationarity means that the first and second moments of the probability density function of

a series are independent of time; however, higher moments are not considered stationary. Detecting the stationarity status of time series is essential for finding the origin of the non-stationarity of the series (Brockwell and Davis, 2011). In the current study, Dickey-Fuller (DF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity tests are utilized as the common stationarity tests.

2.4.1 KPSS method

In the KPSS method, the series is decomposed into the sum of a deterministic trend, a random walk and a stationarity error with the following linear regression model (Kwiatkowski et al., 1992).

$$X_t = r_t + \beta_t + \varepsilon_t, \quad (11)$$

Where X_t is a time series; r_t is a random walk; β_t is a deterministic trend; and ε_t is a stationarity error.

In this model, the series is stationary around a deterministic trend and the null hypothesis will be $\sigma_u^2 = 0$. The residuals e_t ($t=1, 2, \dots, N$) are from the regression of x (each record in a time series) on an intercept and time trend, $e_t = \varepsilon_t$.

The consistent estimation of σ^2 can be constructed from the residuals e_t by Equation 12.

$$\sigma^2(p) = \frac{1}{N} \sum_{t=1}^N e_t^2 + \frac{2}{N} \sum_{j=1}^p w_j(p) \sum_{t=j+1}^N e_t e_{t-j}, \quad (12)$$

where p is the truncation lag and $w_j(p)$ is an optional weighting function.

Then the KPSS statistic is obtained by Equation 13.

$$\text{KPSS} = N^{-2} \sum_{t=1}^N S_t^2 / \sigma^2(p). \quad (13)$$

2.4.2 DF method

The unit root test of DF is one of the most common tests for determining the stationarity of the time series. This test introduces a statistic that has a finite distribution. The performance of this test is carried out using regression models (Wang et al., 2005).

$$y_t = \rho y_{t-1} - 1 + X_t \delta + u_t, \quad (14)$$

where the domain of t is from 1 to N and u_t is a random and independent series. If $|\rho| < 1$, the time series y_t is static and if $\rho = 1$ then the series is not static. The value of $\hat{\rho}$ is calculated using the exponential maximal method by Equation 15.

$$\hat{\rho} = \frac{\sum_{t=2}^N Y_t Y_{t-1}}{\sum_{t=2}^N Y_{t-1}^2}, \quad (15)$$

$$\hat{t} = \frac{\hat{\rho} - 1}{\hat{\sigma}_p}, \quad (16)$$

where $\hat{\sigma}_p$ is the standard least square error for the coefficient $\hat{\rho}$. In this test, the distribution of the test \hat{t} in the H_0 and H_a hypotheses are H_0 ($\rho = 1$) or H_a ($|\rho| < 1$). If the H_a hypothesis is rejected, the series is unstable; while in the case of the rejection of the H_0 hypothesis, the series considers as static.

3 Results and discussion

3.1 Trend detection

3.1.1 Mean air temperature

The results of the serial correlation detection process show the existence of a significant auto-correlation factor among all of the mean air temperature series (Table 2). The TFPW approach should be utilized to modify the results of the M-K test.

Table 2 Serial correlation coefficient of mean air temperature and precipitation time series

Station	Mean air temperature	Precipitation	Station	Mean air temperature	Precipitation
Arak	0.835	0.394	Zabol	0.845	0.281
Ardebil	0.812	0.149	Zahedan	0.840	0.216
Orooomiyyeh	0.843	0.283	Zanjan	0.840	0.282
Esfahan	0.846	0.307	Sabzevar	0.842	0.337
Aqajari	0.852	0.335	Sarakhs	0.831	0.380
Omidiiyyeh	0.844	0.332	Saqquez	0.838	0.333
Ahwaz	0.853	0.295	Semnan	0.845	0.222
Iranshahr	0.846	0.117	Sanandaj	0.847	0.388
Ilam	0.852	0.427	Sahand	0.832	0.231
Abadan	0.851	0.288	Sirjan	0.850	0.220
Abadeh	0.847	0.280	Shahrour	0.840	0.312
Abali	0.844	0.389	Esfahan (East)	0.850	0.280
Babolsar	0.844	0.359	Shahrekord	0.843	0.398
Bojnourd	0.837	0.304	Shiraz	0.852	0.337
Bam	0.838	0.189	Tabas	0.847	0.297
Bandar Anzali	0.841	0.353	Ferdows	0.842	0.380
Bandar Abbas	0.845	0.150	Fasa	0.854	0.283
Bandar Lengeh	0.846	0.177	Qazvin	0.841	0.357
Boushehr (Coastal)	0.847	0.395	Qom	0.847	0.346
Birjand	0.841	0.444	Qouchan	0.834	0.422
Moqan	0.843	0.047	Kashan	0.845	0.228
Tabriz	0.842	0.284	Kerman	0.846	0.238
Torbat Heidariyyeh	0.842	0.383	Karaj	0.839	0.330
Tehran	0.842	0.362	Kermanshah	0.848	0.415
Jask	0.832	0.123	Konarak	0.824	0.129
Boumoussa Island	0.852	0.164	Gorgan	0.842	0.149
Siri Island	0.842	0.195	Maku	0.833	0.290
kish Island	0.849	0.228	Maraqeh	0.843	0.323
Jolfa	0.836	0.275	Masjed Soleiman	0.851	0.294
Chabahar	0.817	0.085	Mashhad	0.836	0.378
Khorramabad	0.849	0.423	Mahabad	0.840	0.366
Khoy	0.832	0.279	Minab	0.843	0.194
Dezfoul	0.849	0.281	Nowshahr	0.844	0.324
Doushan Tappeh	0.840	0.378	Hamedan	0.838	0.383
Dogonbadan	0.854	0.348	Hamedan (Nowjeh)	0.837	0.357
Ramsar	0.844	0.296	Yazd	0.845	0.241
Rasht	0.834	0.316			

The results of the primary M-K test show that both positive and negative trends can be recognized in mean air temperature series; however, this variable follows an increasing trend at most of the stations (about 86%) which is not significant at 95% confidence level. After removing the auto-correlation of the series, the temperature records reveal a downward trend at approximately 73% of the stations. The monthly behavior of mean air temperature shows a significant upward trend at Ardebil station located in the northwestern Iran. However, after applying the TFPW method, the significance of this increasing trend is removed. The temperature series at Konarak station reveals an antithetical behavior after modification of the M-K results; so that after removing serial correlation, the insignificant increasing trend converts to a significant decreasing one. The results

of the Theil-Sen slope estimator illustrate that the maximum slopes for both negative and positive trends are -0.003°C and 0.009°C for Konarak and Ardebil stations, respectively. It is notable that after modifying the results of the M-K test, the trend slopes of most of the series decreases.

Figure 3 illustrates the zoning of mean air temperature trend slopes over Iran. The results of trend slope reveal that mean air temperature series, belonged to a specific climate classification, do not necessarily follow a similar trend. Zoning the trend slopes of mean air temperature records indicates higher warming in the southern Iran compared to the other regions. It is estimated that the upward trend of temperature occurs with lower slopes in the northeast, southwest and southeast parts compared to the other areas. The results of trend identification of mean air temperature show an increasing trend in most of the series which is insignificant at 95% confidence level. The consistent warming of the study region is confirmed by the results of other studies (Houghton et al., 2001; Modarres and da Silva, 2007; Solomon, 2007; Feizi et al., 2014; Field et al., 2014). Researchers around the world have linked the trend analysis of climate variables to the significant signs of climate change. In this regard, numerous studies have shown that the air temperature follows a consistent increase throughout the world (El-Nesr et al., 2010; Gocic and Trajkovic, 2013; Feizi et al., 2014) that is confirmed by assessment report of Intergovernmental Panel of Climate Change (IPCC) (Houghton et al., 2001; Solomon, 2007; Stocker et al., 2013; Field et al., 2014). Contrary to the temperature records, there is no consistent pattern of a trend (positive or negative) for precipitation series which might be its complex nature compared to temperature series (Raziei et al., 2005b; Modarres and da Silva, 2007; Hosseinzadeh, 2014; Zhao et al., 2015). The upward trend of air temperature depends on various factors such as global warming, increase in greenhouse gases concentration with the origin of human activities, increase of cloud cover over the Earth, and urbanization (Samadi et al., 2013). In general, the existence of an increasing trend in air temperature series will result in more drought condition in the region (Feizi et al., 2014).

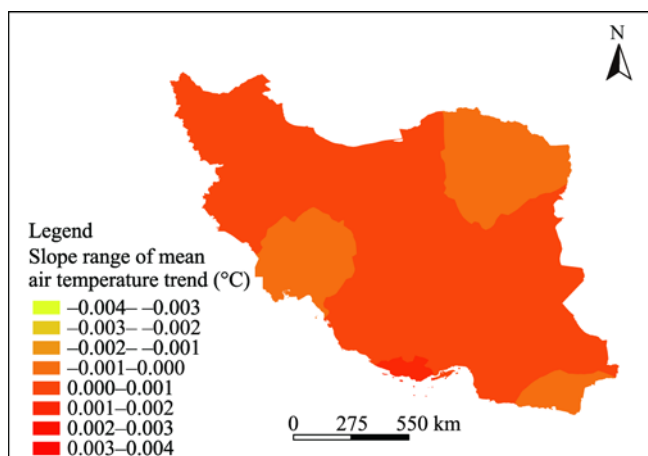


Fig. 3 Slopes of annual mean air temperature trend over Iran from 1985 to 2014

The findings from applying the seasonal M-K test indicates a significant increasing trend at most of the stations; however, about 18% of the series show a significant downward trend. After modification of the test results, the significance of this decreasing trend is eliminated from all stations (except Siri Island). The decreasing trend of some series, e.g., Ilam, Jask, Minab and Sahand stations, changes to an insignificant upward trend. As Figure 4 illustrates, the slopes of trends increase from the southeast to northwest parts of Iran. The seasonal mean air temperature increases with higher slopes in northwestern Iran compared to the other areas. The warming slope decreases as moving gradually towards the central and southeast parts of Iran. This affect the vulnerability of the water resources systems and the safety of the water availability in the region. The increase in temperature, throughout its impacts on the hydrological factors such as evapotranspiration, relative humidity, etc., change the water cycle processes which can cause water resources redistribution (Webb and Nobilis, 2007) and contribute to serious economic, social and political issues.

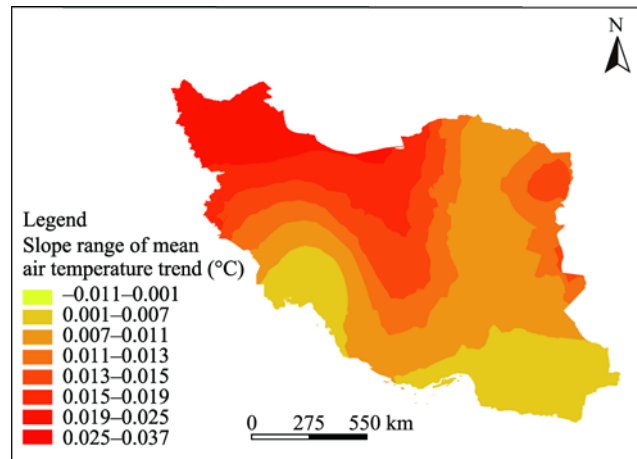


Fig. 4 Slopes of seasonal mean air temperature °C trend over Iran from 1985 to 2014

3.1.2 Precipitation

The results of applying the M-K test on precipitation series show a decreasing trend in about 70% of the selected time series over various climate zones of Iran. This significant increasing trend changes to a downward one after removing the serial correlation factor in some series. According to the statistics of the Theil-Sen slope estimator, the maximum negative and positive trend slopes are -0.016 and 0.012 mm at Rasht and Ramsar stations, respectively. Removing the auto-correlation of time series causes the changes of maximum negative and positive slopes of the series appeared at Rasht (-0.016 mm) and Noshahr (0.012 mm) stations. Both of these stations are located in the very humid climate zone (Fig. 1).

As seen in Figure 5, the observed trend for various precipitation series is not the same in a particular climate zone. In other words, the precipitation series belong to a specific climate classification do not follow the same trend. However, it is observable that the precipitation records of the very humid climate zone, located in the south margins of the Caspian Sea, indicate an upward trend with the higher slopes, while the annual precipitation has a decreasing trend in the east and west margins of the Caspian Sea. The south part of the Urmia Lake, located in northwestern Iran, experiences a decreasing trend with the higher slopes compared to the other regions.

The main findings of this study about the trend of precipitation series are adjusted to the results obtained by Tabari et al. (2011), Some'e et al. (2012), Feizi et al. (2014), and Zohrabi et al. (2014) who investigated precipitation trend throughout different climatic stations over Iran. Similarly, the results obtained about the downward trend of precipitation series in most of the stations in monthly and seasonal scales are in concordance with similar studies in other basins (Masih et al., 2011; Hosseinzadeh, 2014; Fathian et al., 2015). Tabari and Marofi (2011) showed that the variability of precipitation does not follow a single pattern in different parts of Iran and there are both negative and positive trends in different stations and climatic zones. Zohrabi et al. (2014) confirmed that there is a decreasing trend in rainfall data at most of the meteorological stations of Iran during 1968–2008 with increasing temperature. It is expected that rainfall will increase; however, precipitation series indicates a downward trend over arid and semi-arid regions like Iran. The reason for this should be in the geographical condition of Iran. Since Iran is located in the arid and semi-arid region, the amount of moisture is low in the atmosphere and therefore, increasing air temperature causes an increase in moisture capacity and consequently, precipitation will decrease (Feizi et al., 2014).

The seasonal M-K test, measured at different climatic zones, shows a significant decreasing trend at 95% confidence level at most of the stations. After applying the TFPW approach to modify the results of the seasonal trend test, the number of stations which follow a downward trend increases. According to the results of the Theil-Sen slope estimator for seasonal precipitation series the highest slopes of the negative and positive trends were -0.688 and 0.517 mm at Rasht and Ramsar

stations, respectively. After modifying the results, the highest amounts of negative and positive trends become -0.322 and 0.204 mm at Rasht and Maku stations, respectively.

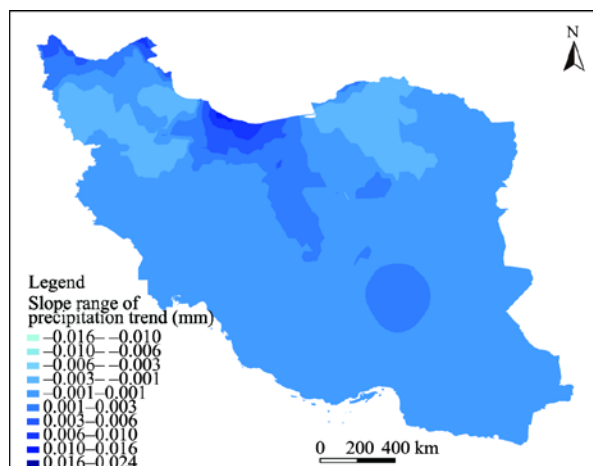


Fig. 5 Slopes of annual precipitation trend over Iran from 1985 to 2014

Analyzing the seasonal trend of precipitation series showed that the slope of the decreasing trends in east and west margins of the Caspian Sea are more than the slopes of negative trend in other studied regions. In various parts of Iran, precipitation variable indicates different trends even when the series belong to a specific climatic zone, indicating the high variability of trend patterns in precipitation series compared to the air temperature ones (Fig. 6).

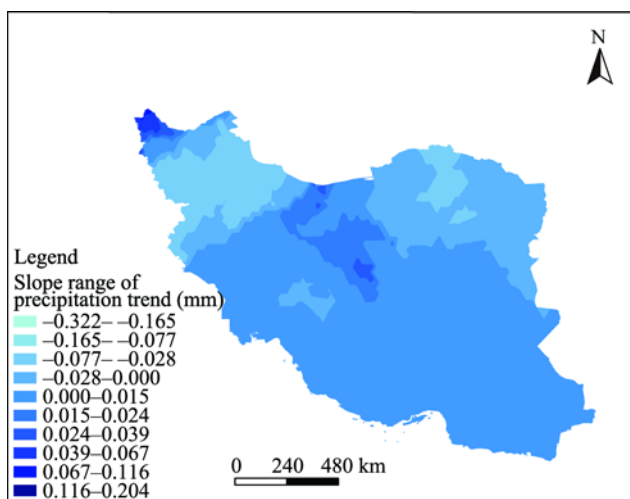


Fig. 6 Slopes of seasonal precipitation trend (mm) over Iran from 1985 to 2014

3.2 Stationarity analysis

The results obtained from the DF unit root test and the KPSS stationarity test show that all of the precipitation series, regardless of the climatic zones where they belong, follow a stationary state (Table 2). This matter is justified in relation to the results obtained from the trend test of precipitation series (Section 3.1.2), which follow a decreasing trend in most of the stations. However, this downward trend is not significant at 95% confidence level. Since significant trend existence is one of the main reasons of time series non-stationarity, the lack of significant trend in precipitation records leads to the stationarity of these series. As it was mentioned previously, the DF test is utilized to determine the presence of unit root in the time series. The outputs of the stationarity analysis revealed that we rejected the null hypothesis, so it can be concluded that the precipitation series is stationary. This matter means that the series can be linear, which shows no significant trend.

Table 2 Stationarity results of precipitation series at 95% confidence level

Station	DF			KPSS		
	Tau	<i>P</i> -value	Hypothesis	Eta	<i>P</i> -value	Hypothesis
Abadan	−19.022	<0.0001	H _a	0.037	0.776	H ₀
Abadeh	−18.483	<0.0001	H _a	0.022	0.970	H ₀
Abali	−18.835	<0.0001	H _a	0.018	0.991	H ₀
Boumoussa Island	−19.379	<0.0001	H _a	0.069	0.358	H ₀
Ahwaz	−19.404	<0.0001	H _a	0.022	0.969	H ₀
Arak	−18.579	<0.0001	H _a	0.022	0.969	H ₀
Ardebil	−18.735	<0.0001	H _a	0.069	0.355	H ₀
Babolsar	−19.427	<0.0001	H _a	0.013	0.999	H ₀
Bam	−19.064	<0.0001	H _a	0.066	0.384	H ₀
Bandar Abbas	−19.451	<0.0001	H _a	0.073	0.325	H ₀
Bandar Lengeh	−19.388	<0.0001	H _a	0.098	0.172	H ₀
Bandar Anzali	−19.069	<0.0001	H _a	0.012	1.000	H ₀
Birjand	−19.094	<0.0001	H _a	0.014	0.998	H ₀
Bojnourd	−18.978	<0.0001	H _a	0.044	0.657	H ₀
Boushehr (Coastal)	−18.789	<0.0001	H _a	0.073	0.325	H ₀
Chabahar	−17.327	<0.0001	H _a	0.058	0.476	H ₀
Dezfoul	−19.041	<0.0001	H _a	0.081	0.264	H ₀
Doushan Tappeh	−18.705	<0.0001	H _a	0.036	0.791	H ₀
Dogonbadan	−18.544	<0.0001	H _a	0.026	0.935	H ₀
Esfahan (East)	−18.715	<0.0001	H _a	0.020	0.979	H ₀
Esfahan	−18.764	<0.0001	H _a	0.013	0.999	H ₀
Fasa	−18.661	<0.0001	H _a	0.028	0.900	H ₀
Ferdows	−19.457	<0.0001	H _a	0.010	1.000	H ₀
Qouchan	−18.911	<0.0001	H _a	0.016	0.995	H ₀
Gorgan	−18.954	<0.0001	H _a	0.04	0.731	H ₀
Hamedan	−18.628	<0.0001	H _a	0.015	0.997	H ₀
Hamedan (Nowjeh)	−18.768	<0.0001	H _a	0.030	0.878	H ₀
Ilam	−18.881	<0.0001	H _a	0.047	0.620	H ₀
Iranshahr	−18.985	<0.0001	H _a	0.082	0.254	H ₀
Jask	−19.070	<0.0001	H _a	0.050	0.567	H ₀
Jolfa	−18.651	<0.0001	H _a	0.063	0.410	H ₀
Karaj	−18.889	<0.0001	H _a	0.021	0.973	H ₀
Kashan	−19.426	<0.0001	H _a	0.018	0.990	H ₀
Kerman	−19.157	<0.0001	H _a	0.039	0.745	H ₀
Kermanshah	−18.574	<0.0001	H _a	0.013	0.999	H ₀
Khorramabad	−19.341	<0.0001	H _a	0.021	0.974	H ₀
Khoy	−18.412	<0.0001	H _a	0.043	0.686	H ₀

To be continued

Continued						
Station	DF			KPSS		
	Tau	<i>P</i> -value	Hypothesis	Eta	<i>P</i> -value	Hypothesis
Kish Island	−19.298	<0.0001	H _a	0.080	0.270	H ₀
Konarak	−18.964	<0.0001	H _a	0.047	0.611	H ₀
Mahabad	−19.249	<0.0001	H _a	0.027	0.914	H ₀
Maku	−18.985	<0.0001	H _a	0.073	0.326	H ₀
Maraqeh	−19.104	<0.0001	H _a	0.031	0.860	H ₀
Mashhad	−19.948	<0.0001	H _a	0.013	0.999	H ₀
Masjed Soleiman	−19.406	<0.0001	H _a	0.019	0.987	H ₀
Minab	−19.460	<0.0001	H _a	0.050	0.575	H ₀
Nowshahr	−19.122	<0.0001	H _a	0.010	1.000	H ₀
Aqajari	−18.919	<0.0001	H _a	0.041	0.706	H ₀
Omidyiyeh	−18.648	<0.0001	H _a	0.042	0.700	H ₀
Oroomiyyeh	−18.620	<0.0001	H _a	0.058	0.470	H ₀
Moqan	−18.018	<0.0001	H _a	0.040	0.729	H ₀
Qazvin	−18.018	<0.0001	H _a	0.015	0.997	H ₀
Qom	−18.838	<0.0001	H _a	0.060	0.448	H ₀
Ramsar	−18.329	<0.0001	H _a	0.018	0.991	H ₀
Rasht	−18.842	<0.0001	H _a	0.016	0.996	H ₀
Sabzevar	−19.386	<0.0001	H _a	0.012	1.000	H ₀
Sahand	−17.720	<0.0001	H _a	0.136	0.069	H ₀
Sanandaj	−18.914	<0.0001	H _a	0.018	0.991	H ₀
Saqqez	−19.602	<0.0001	H _a	0.029	0.894	H ₀
Sarakhs	−19.714	<0.0001	H _a	0.023	0.957	H ₀
Semnan	−19.254	<0.0001	H _a	0.028	0.906	H ₀
Shahrekord	−18.823	<0.0001	H _a	0.013	0.999	H ₀
Shahrud	−19.415	<0.0001	H _a	0.030	0.879	H ₀
Shiraz	−18.677	<0.0001	H _a	0.029	0.898	H ₀
Siri Island	−19.515	<0.0001	H _a	0.093	0.190	H ₀
Sirjan	−19.157	<0.0001	H _a	0.067	0.373	H ₀
Tabas	−19.332	<0.0001	H _a	0.014	0.998	H ₀
Tabriz	−18.502	<0.0001	H _a	0.019	0.984	H ₀
Tehran	−18.997	<0.0001	H _a	0.026	0.929	H ₀
Torbat Heidariyyeh	−19.854	<0.0001	H _a	0.042	0.699	H ₀
Yazd	−18.902	<0.0001	H _a	0.011	1.000	H ₀
Zabol	−19.591	<0.0001	H _a	0.063	0.418	H ₀
Zahedan	−19.251	<0.0001	H _a	0.057	0.486	H ₀
Zanjan	−18.679	<0.0001	H _a	0.027	0.920	H ₀

Note: DF, Dickey-Fuller; KPSS, Kwiatkowski-Phillips-Schmidt-Shin. Tau and Eta are the test statistics of DF and KPSS, respectively.

As shown in Table 4, the mean air temperature series of different climatic zones over Iran are stationary at 95% confidence level. This matter can be rationalized due to the absence of a significant trend. However, the results of the KPSS test results, the mean air temperature series of Konarak station (south of Iran) illustrates non-stationarity at 95% confidence level. As shown in Section 3.1.1, the air temperature records of Konarak station present a significant decreasing trend even after removing the serial correlation of the series and modification of the primary trend results. Considering that the existence of a significant trend is one of the major factors in creating non-stationarity in the time series, the non-stationarity of the mean air temperature series of Konarak station is observable in association with the significant decreasing trend of the records. There are different types of stationarity; however, in the current study, the trend stationarity is investigated to compare and interpret the relationship between the trend and stationarity of the time series. A series that has no unit root but indicates a trend is referred to as a trend stationary series. It is shown that the KPSS test classifies a time series as stationary on the absence of unit root. This means that the series can be trend stationary as it is illustrated about most of the mean air temperature and also all of the precipitation series in the study region. As mentioned previously, non-stationarity can happen as a gradual trend or a sudden shift, so in the current study, the emphasis is on trends and sudden changes. Analyzing the relationships among the stationarity, trend and seasonality of climatic variables can provide useful hints for decreasing the uncertainty of climatic and hydrological simulations and consequently adopting better water resources management strategies in various climatic zones of Iran (Wu et al., 2007).

Table 4 Stationarity results of mean air temperature series at 95% confidence level

Station	DF			KPSS		
	Tau	P-value	Hypothesis	Eta	P-value	Hypothesis
Abadan	-6.728	<0.0001	H _a	0.013	0.999	H ₀
Abadeh	-5.697	<0.0001	H _a	0.022	0.968	H ₀
Abali	-8.147	<0.0001	H _a	0.016	0.995	H ₀
Boumoussa Island	-6.882	<0.0001	H _a	0.013	0.999	H ₀
Ahwaz	-6.487	<0.0001	H _a	0.013	0.999	H ₀
Arak	-10.190	<0.0001	H _a	0.011	1.000	H ₀
Ardebil	-10.704	<0.0001	H _a	0.013	0.999	H ₀
Babolsar	-7.903	<0.0001	H _a	0.012	1.000	H ₀
Bam	-8.180	<0.0001	H _a	0.014	0.999	H ₀
Bandar Abbas	-7.134	<0.0001	H _a	0.013	0.999	H ₀
Bandar Lengeh	-7.256	<0.0001	H _a	0.017	0.992	H ₀
Bandar Anzali	-8.273	<0.0001	H _a	0.012	1.000	H ₀
Birjand	-8.070	<0.0001	H _a	0.013	0.999	H ₀
Bojnourd	-8.572	<0.0001	H _a	0.013	0.999	H ₀
Boushehr (Coastal)	-7.164	<0.0001	H _a	0.012	1.000	H ₀
Chabahar	-8.708	<0.0001	H _a	0.012	1.000	H ₀
Dezfoul	-6.949	<0.0001	H _a	0.119	0.101	H ₀
Doushan Tappeh	-7.880	<0.0001	H _a	0.041	0.714	H ₀
Dogonbadan	-8.050	<0.0001	H _a	0.017	0.993	H ₀
Esfahan (East)	-6.944	<0.0001	H _a	0.013	0.999	H ₀
Esfahan	-7.621	<0.0001	H _a	0.013	0.999	H ₀
Fasa	-9.051	<0.0001	H _a	0.011	1.000	H ₀
Ferdows	-8.107	<0.0001	H _a	0.014	0.998	H ₀
Qouchan	-8.804	<0.0001	H _a	0.012	1.000	H ₀
Gorgan	-8.063	<0.0001	H _a	0.013	0.999	H ₀
Hamedan	-8.232	<0.0001	H _a	0.011	1.000	H ₀

To be continued

Continued

Station	DF		KPSS			
	Tau	<i>P</i> -value	Tau	<i>P</i> -value	Tau	<i>P</i> -value
Hamedan (Nowjeh)	-8.160	<0.0001	H _a	0.020	0.979	H ₀
Ilam	-7.377	<0.0001	H _a	0.016	0.995	H ₀
Iranshahr	-7.172	<0.0001	H _a	0.015	0.997	H ₀
Jask	-8.120	<0.0001	H _a	0.013	0.999	H ₀
Jolfa	-8.371	<0.0001	H _a	0.012	1.000	H ₀
Karaj	-8.333	<0.0001	H _a	0.015	0.998	H ₀
Kashan	-7.470	<0.0001	H _a	0.013	0.999	H ₀
Kerman	-7.510	<0.0001	H _a	0.013	0.999	H ₀
Kermanshah	-7.201	<0.0001	H _a	0.012	1.000	H ₀
Khorramabad	-6.840	<0.0001	H _a	0.013	0.999	H ₀
Khoy	-8.877	<0.0001	H _a	0.012	1.000	H ₀
Kish Island	-7.112	<0.0001	H _a	0.013	0.999	H _a
Konarak	-8.865	<0.0001	H _a	0.266	0.003	H ₀
Mahabad	-8.185	<0.0001	H _a	0.013	0.999	H ₀
Maku	-8.773	<0.0001	H _a	0.012	1.000	H ₀
Maraqeh	-7.876	<0.0001	H _a	0.012	0.999	H ₀
Mashhad	-8.785	<0.0001	H _a	0.012	1.000	H ₀
Masjed Soleiman	-7.454	<0.0001	H _a	0.013	0.999	H ₀
Minab	-7.545	<0.0001	H _a	0.014	0.998	H ₀
Nowshahr	-7.948	<0.0001	H _a	0.014	0.999	H ₀
Aqajari	-6.793	<0.0001	H _a	0.014	0.999	H ₀
Omidyiyeh	-6.810	<0.0001	H _a	0.099	0.166	H ₀
Oroomiyyeh	-7.718	<0.0001	H _a	0.013	0.999	H ₀
Moqan	-7.923	<0.0001	H _a	0.013	0.999	H ₀
Qazvin	-7.992	<0.0001	H _a	0.012	0.999	H ₀
Qom	-7.28	<0.0001	H _a	0.016	0.995	H ₀
Ramsar	-7.945	<0.0001	H _a	0.012	1.000	H ₀
Rasht	-9.003	<0.0001	H _a	0.012	1.000	H ₀
Sabzevar	-7.932	<0.0001	H _a	0.012	1.000	H ₀
Sahand	-8.888	<0.0001	H _a	0.044	0.660	H ₀
Sanandaj	-7.320	<0.0001	H _a	0.012	1.000	H ₀
Saqqez	-8.494	<0.0001	H _a	0.017	0.992	H ₀
Sarakhs	-9.222	<0.0001	H _a	0.011	1.000	H ₀
Semnan	-7.537	<0.0001	H _a	0.012	0.999	H ₀
Shahrekind	-7.714	<0.0001	H _a	0.011	1.000	H ₀
Shahrroud	-8.102	<0.0001	H _a	0.013	0.999	H ₀
Shiraz	-8.998	<0.0001	H _a	0.011	1.000	H ₀
Siri Island	-12.748	<0.0001	H _a	0.039	0.735	H ₀
Sirjan	-7.032	<0.0001	H _a	0.014	0.998	H ₀
Tabas	-7.302	<0.0001	H _a	0.013	0.999	H ₀
Tabriz	-7.897	<0.0001	H _a	0.012	0.999	H ₀
Tehran	-7.929	<0.0001	H _a	0.013	0.999	H ₀
Torbat Heidariyyeh	-8.057	<0.0001	H _a	0.013	0.999	H ₀
Yazd	-7.599	<0.0001	H _a	0.012	1.000	H ₀
Zabol	-7.558	<0.0001	H _a	0.016	0.995	H ₀
Zahedan	-8.005	<0.0001	H _a	0.015	0.997	H ₀
Zanjan	-8.153	<0.0001	H _a	0.012	0.999	H ₀

4 Conclusions

The pressure on natural resources has become a widespread problem in arid and semi-arid regions. In recent decades, this worldwide issue has been intensified as the impacts of climate change have aggregated by the high population growth rate and mismanagement of resources in these areas. Analyzing the stationarity and trends of climatic variables is important for adopting appropriate water resources management strategies, particularly in arid and semi-arid regions (Kahya and Kalaycı, 2004; Kumar et al., 2009). In this study, the last 30-a (1985–2014) spatiotemporal behavior of climate series were discussed according to the monthly precipitation and mean air temperature time series, which belonged to the 73 climate stations of 9 distinct climatic zones over Iran. The classic and seasonal M-K tests were applied for identification of monotonic and seasonal trends of climatic series. Moreover, a pre-whitening approach, namely TFPW, was utilized as a pre-processing approach for removing the effects of auto-correlation of time series on the trend and stationarity test results. Furthermore, KPSS and DF approaches were used to analyze the stationarity of precipitation and mean air temperature time series and the influences of stationarity and non-stationarity of series on trend detection. The main conclusions of the current study are as follows:

- The temperature changes reveal a warming trend since 1985. The mean air temperature warmed more from the northwest to central parts of Iran from 1985 to 2014. This upward trend in mean air temperature, especially in arid and semi-arid zones, has caused different challenges to the population of the region. The most problematic challenges can be seen in the regions where remarkable precipitation decrease is observed with increasing temperature. This is mainly observed in the central parts of Iran with high precipitation variability that makes these parts prone to drought events. The results of mean air temperature trend analysis show that climate may become warmer in future if this increasing trend for air temperature continues.
- The precipitation series follow a downward trend in the majority of the stations over various climatic zones in Iran. However, this downward trend is not significant at 95% confidence level. The precipitation records reveal a non-significant decreasing trend in seasonal scales.
- Spatial patterns of trend and seasonality of precipitation and mean air temperature show that the northwest parts of Iran and marginal areas of the Caspian Sea are more vulnerable to the changing climate with respect to the precipitation shortfalls and warming temperature.
- The stationarity of climatic series has impacts on their trends as the non-stationarity of time series results in their significant trend. The investigation of the average seasonal trend of precipitation and mean air temperature reveal decreasing and increasing trend over the study region, respectively.
- This study developed the first time comprehensive picture of the influence of stationarity on the trends of climatic series. This matter was conducted with applying a corrective pre-processing approach for the trend tests over various climatic zones of Iran. The main conclusions of this study not only suggests the importance and necessity of analyzing the influence of non-stationarity and auto-correlation of climatic series on their trend and seasonality, which is important for providing a comprehensive outlook of the regional climate change in different climatic zones, but also help to improve the practices to cope with the changing condition in a more efficient way. Reviewing and comparing the results of different methods of correction of serial correlation effects with the results corrected by TFPW test in the present study is rewarding and provide useful information to assess the uncertainty that arises from different sources involved in the modelling procedures and consequently lead in more accurate projection results.

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Appendix

Table S1 Characteristics of the selected synoptic stations over Iran

Station	Longitude	Latitude	Altitude (m)	Climatic class
Arak	49°46'E	34°06'N	1708.0	Semi-arid
Ardebil	48°17'E	38°15'N	1332.0	Mediterranean
Oroomiyyeh	45°03'E	37°40'N	1328.0	Semi-arid
Esfahan	51°40'E	32°37'N	1550.4	Extremely arid
Aqajari	49°40'E	30°46'E	27.0	Arid
Omidiyyeh	49°39'E	30°46'N	34.9	Arid
Ahwaz	48°40'E	31°20'N	22.5	Arid
Iranshahr	60°42'E	27°12'N	591.1	Extremely arid
Ilam	46°26'E	33°38'N	1337.0	Mediterranean
Abadan	48°15'E	30°22'N	6.6	Semi-arid
Abadeh	52°40'E	31°11'N	2030.0	Arid
Abali	51°53'E	35°45'N	2465.2	Semi-arid
Babolsar	52°39'E	36°43'N	-21.0	Humid
Bojnourd	57°16'E	37°28'N	1112.0	Semi-arid
Bam	58°21'E	29°06'N	1066.9	Extremely arid
Bandar Anzali	49°27'E	37°29'N	-23.6	Very humid
Bandar Abbas	56°22'E	27°13'N	9.8	Extremely arid
Bandar Lengeh	54°50'E	26°32'N	22.7	Extremely arid
Boushehr (Coastal)	50°49'E	28°54'N	8.4	Arid
Birjand	59°12'E	32°52'N	1491.0	Arid
Moqan	47°55'E	39°39'N	31.9	Semi-arid
Tabriz	46°17'E	38°05'N	1361.0	Semi-arid
Torbat Heidariyyeh	59°13'E	35°16'N	1450.8	Semi-arid
Tehran	51°19'E	35°41'N	1190.8	Arid
Jask	57°46'E	25°38'N	5.2	Extremely arid
Boumoussa Island	54°50'E	25°50'N	6.6	Extremely arid
siri Island	54°29'E	25°53'N	4.4	Extremely arid
kish Island	53°59'E	26°30'N	30.0	Extremely arid
Jolfa	45°40'E	38°45'N	736.2	Mediterranean
Chabahar	60°37'E	25°17'N	8.0	Extremely arid
Khorramabad	48°17'E	33°26'N	1147.8	Semi-arid
Khoy	44°58'E	38°33'N	1103.0	Semi-arid
Dezfoul	48°23'E	32°24'N	143.0	Arid
Doushan Tappeh	51°20'E	33°42'N	1209.2	Semi-arid
Dogonbadan	50°49'E	30°20'N	726.0	Semi-arid
Ramsar	50°40'E	36°54'N	-20.0	Very humid
Rasht	49-37'E	37-19'N	-8.6	Very humid
Zabol	61°29'E	31°02'N	489.2	Extremely arid
Zahedan	60°53'E	29°28'N	1370.0	Extremely arid
Zanjan	48°29'E	36°41'N	1663.0	Semi-arid
Sabzevar	57°39'E	36°12'N	972.0	Arid
Sarakhs	61°10'E	36°32'N	235.0	Arid
Saqquez	46°16'E	36°15'N	1522.8	Mediterranean
Semnan	53°25'E	35°35'N	1127.0	Arid
Sanandaj	47°00'E	35°20'N	1373.4	Mediterranean

To be continued

Continued

Station	Longitude	Latitude	Altitude (m)	Climatic class
Sahand	46°07'E	37°56'N	1641.0	Semi-arid
Sirjan	55°41'E	29°28'N	1739.4	Extremely arid
Shahrroud	54°57'E	36°25'N	1349.1	Arid
Esfahan (East)	51°52'E	32°40'N	1543.0	Extremely arid
Shahrekord	50°21'E	32°17'N	2048.9	Very humid
shiraz	52°36'E	29°32'N	1484.0	Semi-arid
Tabas	56°55'E	33°36'N	711.0	Extremely arid
Ferdows	58°10'E	34°01'N	1293.0	Arid
Fasa	53°41'E	28°58'N	1288.3	Semi-arid
Qazvin	50°03'E	36°15'N	1279.2	Semi-arid
Qom	50°51'E	34°42'N	877.4	Arid
Qouchan	58°30'E	37°04'N	1287.0	Semi-arid
Kashan	51°27'E	33°59'N	982.3	Extremely arid
Kerman	56°58'E	30°15'N	1753.8	Arid
Karaj	50°54'E	35°55'N	1312.5	Semi-arid
Kermanshah	47°09'E	34°21'N	1318.6	Semi-arid
Konarak	60°22'E	25°26'N	12.0	Extremely arid
Gorgan	54°24'E	36°54'N	0.0	Mediterranean
Maku	44°26'E	39°20'N	1411.3	Semi-arid
Maraqeh	46°16'E	37°24'N	1477.7	Semi-arid
Masjed Soleiman	49°17'E	31°56'N	320.5	Semi-arid
Mashhad	59°38'E	36°16'N	999.2	Semi-arid
Mahabad	45°43'E	36°45'N	1351.8	Semi-arid
Minab	57°05'E	27°06'N	29.6	Arid
Nowshahr	51°30'E	36°39'N	-20.9	Very humid
Hamedan	48°32'E	34°52'N	1741.5	Semi-arid
Hamedan (Nowjeh)	48°43'E	35°12'N	1679.7	Semi-arid
Yazd	54°17'E	31°54'N	1237.2	Extremely arid