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Investigating the Trend of Temperature Changes in Isfahan Station, Iran Using the Sequential Mann-Kendall Method

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Abstract

During recent decades, global climate change has been one of the most important research topics in the study of the earth, and its consequences have been reported in many types of research. The aim of this research is to investigate the trend of monthly, seasonal and annual temperature changes in Isfahan province, Iran using the non-parametric Mann-Kendall test. In this research, to investigate the trend of temperature changes in Isfahan, the mean monthly, seasonal, and annual temperature data during a 67 years period (1951-2017) has been used. Then, the occurrence time and direction of trend of all studied temperature series were specified using sequential Mann-Kendall test. The statistical analysis of the results showed that all three parameters are distributed symmetrically and follow the normal distribution. The results showed that the mean monthly temperature time series had non-significant trend at level of 5%. The average seasonal trend of temperature using the sequential Mann -Kendall test indicates non-significant trend in the winter and an increasing trend in other seasons, but this trend is nonsignificant at level of 5%. The results revealed an increasing trend in the annual temperature series, which was significant at level of 5%.

Keywords: Climate Changes, Non-Parametric test, Temperature, Time Series.

1. Introduction

Climate, as the most influential factor in human life and in general the life of living organisms, has shown many small and large changes since the past. Except catastrophic (rapid and sudden) climate changes, which are considered by many paleoclimatologists and geologists, climate changes are usually slow and gradual and may not be noticeable in a short period of several years (Mohammadi, 2012). A slight disruption of the world's climate balance has caused the average temperature of the globe to show a tendency to increase. Temperature can be considered one of the most important elements of the climate system, whose changes can change the weather conditions of any region. These changes can occur in various ways. Information about temperature has been used a lot in the implementation of scientific and economic goals, especially in recent years. Although the effects of environment temperature are important in other fields such as medicine, but its geographical aspects are more commonly used. Due to the importance of temperature in socio-economic planning, the study of its behavior in long (trend) and short-term periods (for example, annual cycles) during the last few decades has attracted the attention of scientists. (Asakereh and Kheradmandnia, 2002). The application of statistical methods in order to understand the linear and non-linear behavior of climatic elements is one of the best methods for evaluating the long-term climatic variable's trend. The trend of temperature and precipitation is not the same all over the world. Climate change does not necessarily mean changes in precipitation and temperature (Clarke, 2003). On the other hand, proving the existence of a significant trend in a time series of precipitation alone cannot be a conclusive proof of the occurrence of climate change in a region, but fortifying the assumption of its occurrence (Serrano et al., 1999). In order to detect the trend in the time series of hydro meteorological variables, various tests are used, and these tests can be divided into two main categories, parametric and non-parametric. Parametric tests are more powerful in detecting trends than non-parametric tests, and when using them, the data should be random (independent) and have a normal distribution. On the other hand, non-parametric tests can be used if the data are random and are not sensitive to the normality of the data. Mann-Kendall and Spearman's rho tests are examples of non-parametric tests that are used in many researches on the trend of hydro meteorological variables around the world (Sabziparvar and Shadmani, 2011). The Mann-Kendall test have been used by many researches in Iran and other parts of the world to reveal and recognize the trend in hydro-meteorological time series, among which the following can be mentioned: Omidvar and Khosravi (2010) used the Mann-Kendall test to reveal the trend in five meteorological variables in the northern coasts of the Persian Gulf, including minimum temperature, maximum temperature, average temperature, relative humidity and precipitation of three synoptic stations of Bandar Abbas, Bushehr and Abadan in fifty years (1956-2005) period. The results of the research showed that the trend of average temperature time series in all three stations are similar to their minimum temperature trend. It was concluded that the increase in the average temperature of the regional stations was mostly due to the changes in minimum temperature. Zareabyaneh et al. (2011) analyzed the trend of climatic factors of precipitation, temperature and drought in two seasonal and annual scales in 15 stations of Hamedan province, Iran. The results showed that the trend of annual precipitation in 60% of the stations was decreasing, and this decreasing trend was mostly directed towards spring, winter and summer seasons. Also, the examination of temperature changes has shown that the annual temperature trend of 50% of the stations has increased significantly. Faizi and Norozi (2010) studied the climate change in Sistan and Baluchistan province using Mann-Kendall method. For this purpose, they used the data of the stations (Zahedan, Zabol, Iranshahr and Chabahar) in the period of 1996-2005. The results showed that all stations, except Zahedan, had a significant negative trend in temperature. Sabziparvar and Shadmani (2011) analyzed the trend of reference evapotranspiration in arid areas of Iran using the Mann-Kendall and Spearman rho tests. The results showed that the most significant increasing trend of monthly reference evapotranspiration was experienced at Birjand station, but no significant trend was observed in Bandar Abbas, Sabzevar and Semnan stations. In annual scale, Mashhad station has shown the highest amount of increasing trend of reference evapotranspiration with a slope of 7.50 mm per year. Mohammadi (2012) examined the trend of the annual and seasonal precipitation in Kurdistan province using non-parametric tests during a 45 years period (1976- 2011). The obtained results confirmed the existence of some significant trends in annual and seasonal precipitation of the studied stations. Zohrabi et al. (2016) investigated the temporal and spatial changes of climatic variables of temperature and precipitation in the Karkheh watershed located in the west of Iran using Mann-Kendall, Spearman and Sen's slope tests. They have used the data of 88 stations during the period of 1971-2011. The results indicated an increasing and decreasing trend in annual temperature and precipitation, respectively, at 5% significance level for most of the studied stations. Ansari et al. (2017) studied the trend of changes in temperature, precipitation and discharge in the Kajo river watershed, Iran in a 20-year period using the Mann-Kendall test. The result showed that the precipitation in the area has a decreasing trend, but the temperature has an increasing trend. The river discharge had a decreasing trend during the studied period. Darabi et al. (2016) studied the trend in the precipitation, temperature, wind speed and relative humidity in Qom, Iran using Mann-Kendall method in 35-year period. They have detected an increasing trend in the average minimum and average annual temperature. Kousari et al. (2017) investigated the trend of drought occurrence in the arid and semi-arid regions of the world using the non-parametric Mann-Kendall test. For this purpose, they calculated the standardized precipitation index (SPI) in different time scales. The result showed that with increasing the scale of the SPI time series, the percentage of areas experienced the increasing or decreasing trend in drought become more. Binesh et al. (2017) have investigated the seasonal and annual trend of monthly temperature and precipitation time series of Tehran province using graphical regression and Mann-Kendall tests. Then, the anomalies of temperature and annual average precipitation have also been calculated and analyzed by estimating the moving average. The results of this research showed a slight and insignificant increase in the temperature of Tehran, and the temperature changes were made with a mild slope. The precipitation had no significant trend in the studied period. In a research, Torkaman et al. (2019), analyzed the trend of climatic variables of Khuzestan province using Mann-Kendall test. For this purpose, meteorological variables, including temperature, rainfall, evapotranspiration and relative humidity for 15 meteorological stations in a 21-year period (1996-2016) were used. They reported the decreasing trend of rainfall and relative humidity as well as the increasing trend of temperature variables and evapotranspiration in most of the stations of the province, which indicated the effect of climate change in the studied area. Ghahhari et al. (2015) studied the trend of temperature changes at synoptic station in Shiraz using the Mann-Kendall method over a period of 42 years (1972-2011). The results of their research showed that despite the absence of a significant trend in the long-term period, the absolute minimum daily temperature in Shiraz has been decreasing significantly. The annual absolute maximum daily temperature of Shiraz is increasing with an increasing slope, which indicates the gradual increase of maximum temperatures and the intensification of summer heat. Ghasemi (2017) studied the trend of temperature changes using Mann-Kendall method in four cities of Chaharmahal and Bakhtiari province during a 25-year period (1988-2012). The results showed that March with 100% trend, showed the most change and December showed the least change with 85% without significant trend. It also showed a negative trend with 30% in the winter season, a sudden increase change with 55% in the spring season, a positive trend with 35% in the summer season, no trend with 55% in the fall season, and a sudden increase change with 35% in the annual changes. Also, in winter and summer with 90%, the most change was observed and in autumn with 45%, the least change was observed. In the annual time scale, 75% trend and 25% no trend was observed. Mazidi and Toofani (2021) studied the trend of changes in temperature and precipitation at synoptic station in Urmia using the Mann-Kendall method during a 15-year period (1996-2010). The results of their research showed that the trend of temperature in Urmia is decreasing with a low slope, and the absence of precipitation in Urmia is increasing with a high slope.

Tomozeiu et al. (2000) investigated the variability of average winter rainfall in Amilliard and Magna, Italy, using the Man-Kendall method and orthogonal empirical functions, and reported that all stations have a decreasing trend in winter rainfall. Gemmer et al. (2004) studied the monthly precipitation trends in China and showed that the number, distribution, and decreasing trends vary from month to month. Yang et al. (2012) investigated the 53-year average monthly temperature and precipitation trends in the Zhangweinan River basin and five meteorological stations around it using the Mann-Kendall test and reported a significant decreasing trend in annual precipitation and an increasing trend in temperature in the spring and summer. Jain et al. (2013) investigated the long-term changes of precipitation and temperature in North-West India. They used Mann-Kendall method to detect trends and did not observe any significant trend in the monthly, seasonal, and annual time scales of precipitation in the period of 1978-2008, but the temperature in all three time scales has an increasing trend. Chen et al. (2014) investigated the trends of precipitation, temperature, and runoff in the Yangtze catchment area of China in the period of 1955-2011 using the Mann-Kendall test. The results showed that the average temperature had an increasing trend, the precipitation did not experience any significant changes, and the runoff had an increasing trend. Xu et al. (2015) studied the trend of precipitation in the dry regions of Central Asia from 1950 to 2000. Trend analysis have been conducted on monthly rainfall data of 344 meteorological stations from 1950 to 2000. The results indicated that 17.4 percent of precipitation has increased in all meteorological stations during the studied period.

Numerous studies have been used the Mann-Kendall test for trend analysis around the world (Alemu and Dioha, 2020; Gadedjisso Tossou et al. 2021; Hedayati-Dezfuli and Fazel-Rastgar, 2020; Iyakaremye et al. 2022; Haq, 2022; Hırca et al., 2022). The purpose of this research is to investigate the trend of temperature changes in the Isfahan station using the sequential Mann-Kendall method during a 67 years period (1951-2017

2. Materials and Methods:

2.1. Study area and used data

Climatic parameters change in time and space for many reasons, and the pattern of their changes should be determined based on observations and using statistical methods. Trend analysis is one of the usual approaches that have been widely used to detect the temporal changes in time series and evaluating the potential impacts of climate change on temperature, precipitation, river flow, etc. in different parts of the world. The trend analysis methods are divided into two main categories: parametric and non-parametric. Parametric methods are mainly based on the regression relationship between the data series and time. Non-parametric methods mainly determine the value of data points based on the signs and rank of the data in an ascending or descending order. The Mann-Kendall method is one of the widely used methods for trend analysis, which has been used in many studies to detect trends in hydroclimatic time series. The null hypothesis for this test states that all observations are independent; on the other hand, the alternative hypothesis assumes that a monotonic trend, positive or negative, exists in the time series. In this research, in order to investigate the trend of temperature changes in Isfahan, the sequential Mann-Kendall test were used. For this purpose, the monthly, seasonal and annual temperature data of Isfahan station during 1951-2017 was used. Isfahan city is located on 51° 40' 17" E east longitude and 32° 39' 34" N north latitude (Fig. 1). The area of this city is about 493.8 square kilometers. The general characteristics of the mean annual temperature of Isfahan city are presented in Table (1). The statistics presented in Table (1) are calculated for a 67-year period (1951-2017).

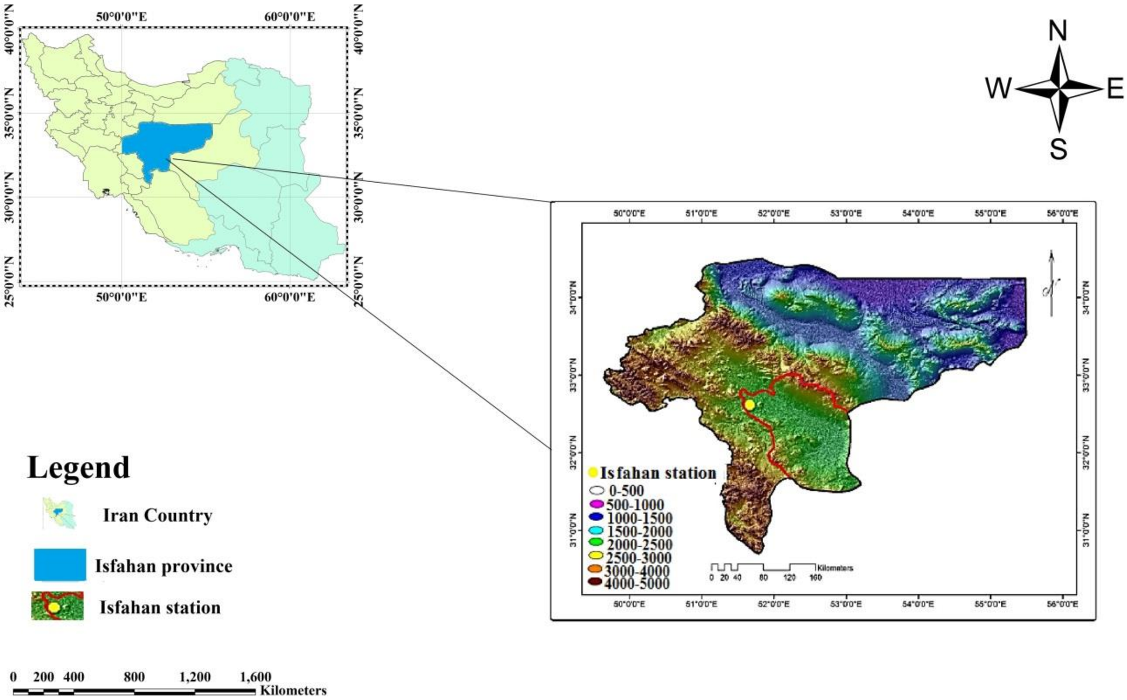

Fig. 1. Location map of Isfahan station in Iran.

Table 1. Statistical characteristics of annual temperature of Isfahan station.

Statistical characteristics	Average	Median	Mode	Variance	SD	Skew	Kurtosis	Min	Max	r
Temperature	16.48	16.57	15.34	0.79	0.89	-0.1	-0.05	14.25	18.74	4.49

Mann-Kendall (MK) test was first introduced by Mann (1945) and then developed by Kendall (1975) based on the rank of data in a time series. One of the strengths of this test is its suitability for time series that do not follow normal distribution. Also, this method is not sensitive to outlier values which may exist in the time series (Hejam, 2008). The steps of applying the sequential MK test are as follows:

First, values of the original series (x_i) are replaced by their ranks (y_i), arranged in ascending order.

Then, the magnitudes of y_i, (i = 1,..., N) are compared with y_j, (j = 1,...,i−1). At each comparison, the number of cases $y_i > y_j$ need to be counted and denoted by n_i.

A statistic t_i can, therefore, be defined as follows:

$$t_i = \sum_{i=1}^{n} n_i \quad (1)$$

Mathematical mean and variance of test statistic (t_i) can be calculated by Eqs. (2) and (3).

$$E_{(t_i)} = \frac{i(i-1)}{4} \quad (2)$$

$$V_{(t_i)} = \frac{[i(i-1)(2i+5)]}{72} \quad (3)$$

The sequential values of the statistic U(t_i) can be calculated by equation (4):

$$U_{(t_i)} = \frac{[t_i - E(t_i)]}{\sqrt{V_{t_i}}} \quad (4)$$

U values are significant when an increasing or decreasing trend is observed, which depends on its value being less or more than zero. In order to identify small and short-term trends, jump points and starting points of the time series trend, the values of U′(t_i) can be computed backward similarly as the forward series but starting from the end of the series, and then U(t_i) and U′(t_i) can be plotted to detect the abrupt change in time series Mathematical mean, variance and U´(t) statistic can be calculated by equations 5 to 7, respectively (Snyder and Hoffman, 2002).

$$E'_{(t_i)} = \frac{[N-(i-1)(N-i)]}{4} \quad (5)$$

$$V_{(t_i)} = \frac{[N-(i-1)(N-i)][2(N-(i-1)]+5}{72} \quad (6)$$

$$U'_{(t_i)} = -\frac{\sum t'_i - E'(t_i)}{\sqrt{V'(t_i)}} \quad (7)$$

After calculating the above values, two values U and U′ will be drawn in the form of a graph. These graphs can show three different types of changes:

Sudden changes: If the meeting point of two curves U and U′ is inside the critical range and the U curve leaves the critical limit and returns to the range again, the changes will be sudden. Trend: If the U-curve does not return to the range after leaving the significant range, the trend will be significant. There will be a positive trend towards positive values and a negative trend towards negative values.

Without significant change: if the two mentioned curves collide with each other within the critical range and do not leave the critical range or there is no intersection, or the curves overlap several times towards the end of the time series, there is no significant trend in time series (Alijani et al., 2011). In order to apply the sequential MK test, a code was written in MATLAB.

3. Results and Discussion

According to the Table (1) (Table of the previous section) , it can be see that the values of all three measures of central tendency, i.e. mean, median, and mode, are almost close to each other. It indicates that the shape of the distribution is symmetrical and close to the normal distribution. The proof of this claim can be found in the low skewness coefficient (-0.1) that is very close to the normal distribution which has zero skewness. On the other hand, according to the negative sign of the skewness number, we can understand that the shape of frequency distribution tends to high values. It means that the frequency of values higher than the average is more than the frequency of values lower than the average. The coefficient of kurtosis is used to express the flatness or peakedness of the distribution curve compared to the normal distribution curve (Asakereh, 2011). When the skewness characteristic is positive, the values higher than the average in the data observed more than the maximum values lower than the average, so it is said that the distribution is skewed. The negative value of kurtosis indicates the elongated shape of the distribution and the distribution has lighter tails than the normal distribution. Taking into account that the coefficient of kurtosis of

Isfahan temperature is -0.05, it means that its distribution elongation is low.

3.1. Temperature trend using Mann-Kendall test

3.1.1. Mean monthly temperature

The results of applying the sequential MK test on the average monthly temperature are given in Figs. (2) and (3). As can be seen in Figure (2-A), in the month of January, two curves U_i and U_i' have crossed each other during the years 1974, 1980, 1984, 1985, 2015, so it can be said that the trend started from these points, but considering that the meeting points of the two curves U_i and U_i' was inside the critical range, i.e. (±1.96), the trends that occurred are not significant at 5% level. Also, considering that the U_i and U_i' lines are almost apart, it can be concluded that a sudden trend has happened in the time series.

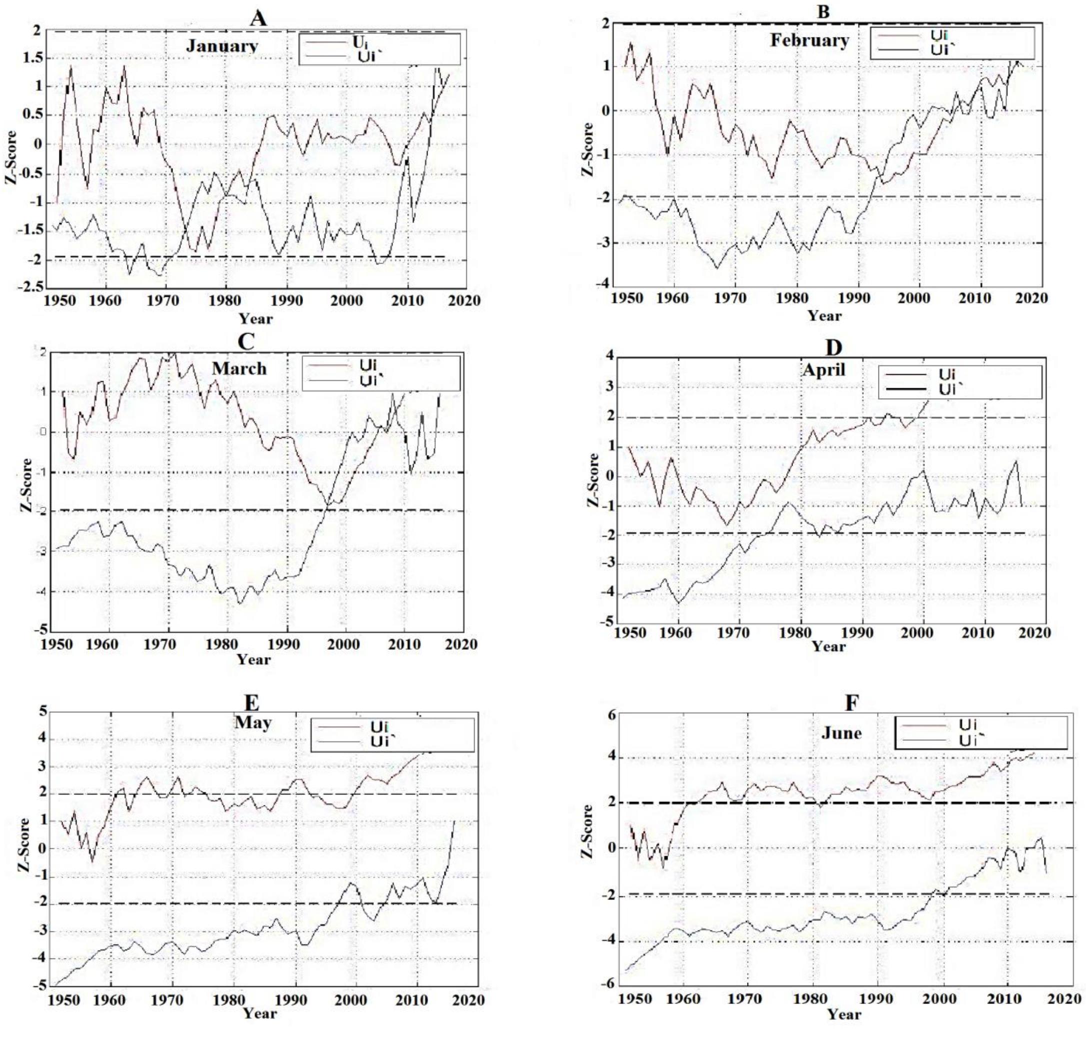

Fig. 2. The curves (U_i and U_i') of sequential Mann-Kendall test for the months of the year during the period 1951-2017.

Figure (2-b) shows the U_i and U_i' for February temperature. According to this Figure, it can be seen that jump point has occurred in 1994. After 1994, there have been several collisions in a short period of time (2010, 2015 & 2016), which indicates the absence of a significant trend. Because the two curves (U_i and U_i') have collided within the significance limit, so the trend is not significant. Also, the time where these points intersect each other is the starting point of the trend process. It is worth mentioning that the U_i and U_i' lines were far apart at the beginning of the time series and where the jump occurred, these lines have come closer together, which indicates the occurrence of a slow trend in the time series of the studied data, in other words, approximately from 1994 until the end of the period, a low trend towards positive values dominates the temperature of this month.

Figure (2-C) shows the average temperature changes during March in the studied period. As it can be seen, the curves U_i and U_i' have intersected each other within the significant range during the years 1997, 2006, 2007, and 2009. Where these points have intersected each other, the time series trend has started, and the mentioned points are the milestones of this month. In other words, it can be said that an abrupt change has occurred with an increasing process.

Figures (2-D, E, F) and (3-G) indicating that the U_i curve did not intersect with the U_i' curve in any of the months of April, May, June, July, but uniformly in all three graphs. It has risen above the significant limit of +1.96.

Figure (3-H) shows the curves of sequential Mann- Kendall test for the month of March. According to this Figure, it can be seen that two curves U_i and U_i' have crossed within the significant boundary in the years 1957 and 1958. Considering the distance between the two curves and the fact that the U_i curve has left the critical limit of +1.96 and has not returned to the non-significance interval, this indicates the occurrence of an increasing sudden change. The months of April, May, June and July had similar pattern. As can be seen in Figure (3-K), in the month of November, like the previous months, two curves U_i and U_i' have crossed during the years 1958, 1959, 1986, 1987, and 1988, so it can be said that the trend started from these points, considering that the meeting time of the two curves U_i and U_i' was inside the critical range, i.e. (±1.96), the trends that occurred are not significant. Therefore, a series of insignificant trends can be deduced. According to the departure of the U_i curve and the return of the mentioned curve to the significant range and the distance between the two curves (U_i and U_i'), it can be detected a sudden trend. In the month of December, the behavior is similar to the October, with the difference that two components (U_i and U_i') have crossed in 1974 and 1977. The results for other months are given in Figures 3-I, J &L.

3.1.2. Average seasonal temperature

Applying the sequential Mann-Kendall test on the average temperature during different seasons during the studied period in Isfahan station shows the absence of significant changes except in the winter season (Figure 4). In the seasons of spring, summer and autumn, it shows an increasing trend during the study period, considering that despite the fact that the U_i -curve did not intersect with the U_i'-curve, it exceeded the significance limit of +1.96 in all three mentioned seasons. In the winter, considering that the meeting point of the two curves U_i and U_i' was inside the critical range, i.e. (±1.96), the trend is not significant. As can be seen, these two curves intersected in 2000, so it can be said that the trend started from this point and the trend is increasing.

3.1.3. Annual temperature

The results of Kendall's test show that the annual temperature of Isfahan has been increasing in recent years. As can be seen, the u-curve has exceeded the significance limit of +1.96. Therefore, examining the behavior of the changes in the U_i and U_i' components reveals that there is no significant jump in the annual time series and the temperature has experienced the natural upward trend in Isfahan station (Figure 5).

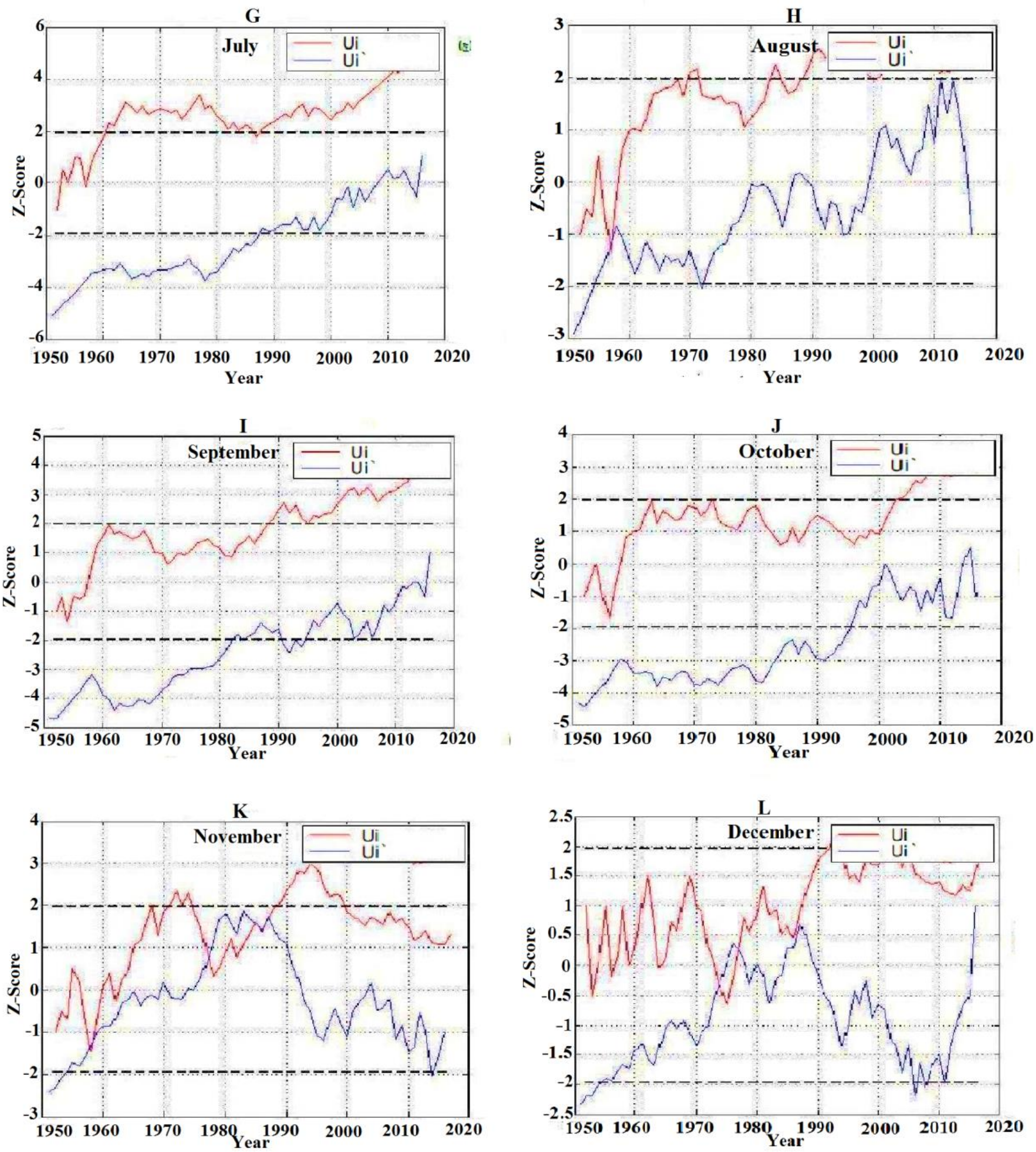

Fig. 3. The curves (U_i and $U_i{'}$) of sequential Mann-Kendall test for the months of the year during the period 1951-2017.

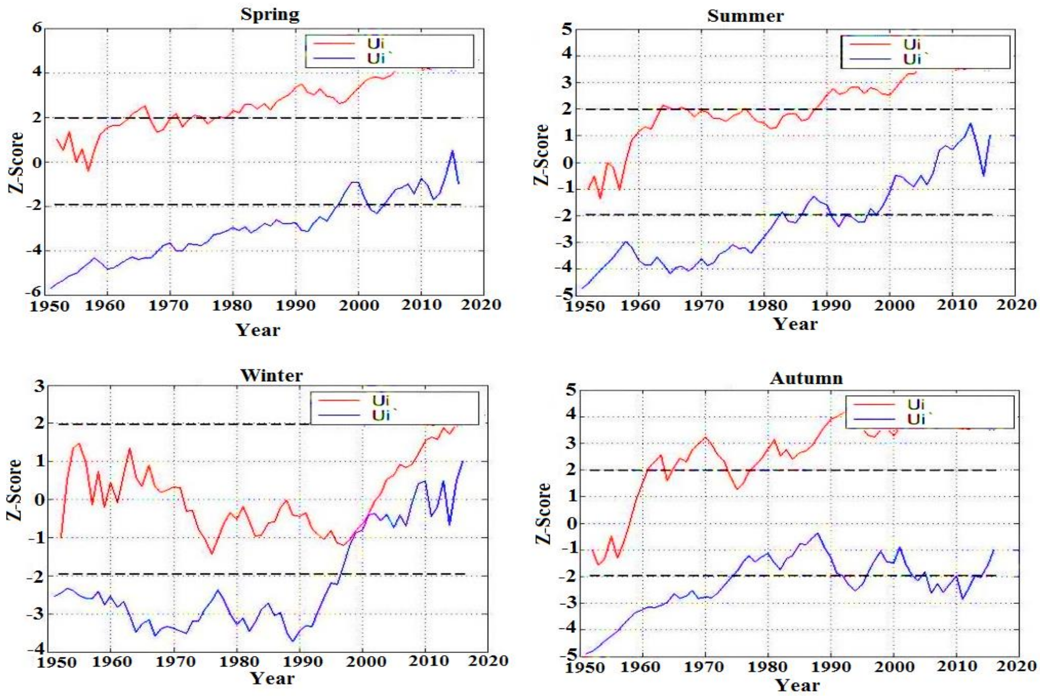

Fig.4. The curves (U_i and U_i') of sequential Mann-Kendall test for the seasons of the year (1951- 2017).

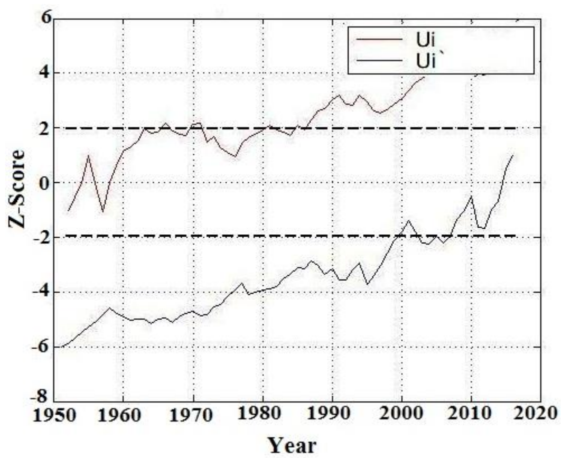

Fig. 5. The curves (U_i and U_i') of sequential Mann-Kendall test for annual temperature in Isfahan station (1951- 2017).

The results of this research are consistent with the studies of Yang et al. (2012) which reported increasing trend of temperature in spring and summer in the Zhangunian river basin, China. Also, the increasing trend of temperature have been reported in the study of Jain et al. (2013) in North-West India. Some other studies have also reported increasing trend in temperature series around the world (Gadedjisso et al., 2020; Alemu et al., 2021; Mohamed et al., 2021; Hedayati-Dezfuli & Fazel-Rastgar, 2020).

4. Conclusion

Studying the long-term changes of hydroclimatological variables and their effects on different parts of the hydrological cycle can provide useful information for predicting the water needs of different consumption sectors in the future and, accordingly, water resources management for planners and designers. Climate changes and its effects on water resources and environment have attracted the attention of researchers in recent years. In this research, the trend of temperature changes in Isfahan, Iran was studied. For this purpose, the trend of the average monthly, seasonal, and annual temperature time series were analyzed using the sequential Mann-Kendall test. The results of this study indicated that in most of the months of the year (January, February, March, August, November and December) two curves U_i and U_i' have crossed each other inside the significant limits indicating that the temperature did not experienced significant trend. In seasonal time scale, except the winter, in other seasons, the two curves of U_i and U_i' are almost parallel to each other. Therefore, it can be concluded that no sudden changes have occurred in spring, summer and autumn at a significant level of 5%. In the winter season, a sudden change in 2000 was detected in the temperature time series. An increase in temperature will lead to an increase in evapotranspiration and agricultural water demand. Due to the increasing population growth and the development of industries in Isfahan province, in recent decades, this province has been facing a water shortage, and the increase in temperature has also worsened the situation. Therefore, it is necessary to manage water resources and reduce water consumption, especially in the agricultural sector by changing the cultivation pattern and using pressurized irrigation methods instead of traditional methods.

5. Disclosure statement

No potential conflict of interest was reported by the authors.

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