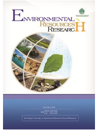

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Annual air temperature change characteristics in the Hamedan region of Iran

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Abstract
In this research air temperature characteristics of five meteorological stations located in the Hamedan region of Iran were analyzed. The main objective was to identify and assess the possible climate change of the region during the period 1980 to 2010. To this end, time series of the mean annual temperature were investigated using Mann-Kendall and Normalized Residual Mass Curve methods. The climatological stations were Hamedan, Ekbatan Dam, Dargazin, Nojeh and Varayaneh. The results showed that the Mann-Kendall and Normalized Residual Mass Curve tests were similar on detection of the trends. The mean annual temperatures of stations with the exception of Varayaneh and Darghazin showed significant rapid increasing trends. This study illustrates the identical results of the two different tests on climate change identification and more importantly a significant warming at the majority of stations in the region. These results provide useful information for long term planning in water management of the region.

***Keywords*: Annual air temperature; Mann-Kendall; Normalized Residual Mass Curve**

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Introduction

During the lasts fives decades, atmospheric carbon dioxide levels have recorded a continual increase, which has significantly altered the global and local climate characteristics such as temperature and precipitation (Yu et al. 2002). It showed that floods previously considered rare have occurred more frequently in certain regions while drought-related and competing water issues have intensified in other regions. Climate change would further affect flow regimes and water resources through impact on rainfall distribution patterns, magnitude and intensity of individual precipitations, evaporation arising from temperature and radiation changes, and alternations in vegetation response (Matondo & Msibi 2001).

Nicholls (1996) emphasized that further work on analyzing changes in climatic extremes was required. Frich (2002) compiled a new global dataset of derived indicators to clarify whether frequency or severity of climatic extremes changed during the second half of the 20th century. To this aim, the time series which had 40 years or more of almost completed records were used. Coherent spatial patterns of statistically significant changes emerged, particularly an increase in warm summer nights, a decrease in the number of frost days and a decrease in the intra-annual extreme temperature range.

Folland (2001) revealed that average global surface temperature has increased by about 0.6 ± 0.2 °C since the late 19th century. He pointed out that the 1976-2000 warming was largely globally synchronous, but were more pronounced in the Northern Hemisphere during winter and spring. Folland (2000) also showed that minimum temperatures increased at nearly twice the rate of maximum temperatures during the period from 1950 to 1993.

Gallego (2006) collected daily rainfall data from 35 stations distributed throughout the Iberian Peninsula for the period 1958 to 1997. He divided the data into four categories including light (between 0.2 and 2.5 mm per day), moderate (2.5 to 7.5 mm), intense (greater than 7.5 mm), and very intense (greater that 15 mm). He used a Mann-Kendall test to determine if significant trends existed in the data and showed that the real distribution of the daily Peninsula precipitation was becoming ever more asymmetric.

Long term trends in the four regions of Japan were also investigated based on annual and monthly precipitation (Yue & Hashino 2003). The statistical significance of a trend at a study site was assessed by the Mann-Kendall test, and significance of trends in climatic regions (called II, III, and IV) was evaluated using the bootstrap test preserving cross correlation. The practical significance of a trend was judged by a percentage change of the sample mean over an observation period.

In Iran, the influence of the Arctic Oscillation (AO) on winter Surface Air Temperature (SAT) from 1951 to 2000 was investigated using the Median Sequential Correlation Analysis (MSCA) technique by Ghasemi and Khalili (2006). The results demonstrated that winter SAT were negatively correlated with the winter AO index for most parts of the country. The winter AO index accounted for about 14 to 46% of the winter SAT variance. The positive SAT anomaly was found to be associated with the onset of the negative phase. These results also indicated that the summer climate was linked to changes in atmospheric circulation which persist through to the following autumn and winter.

Ghasemi and Khalili (2008) also attempted to find possible linkages between the North Sea-Caspian pattern (NCP) index and the winter temperature variability over Iran. The result showed that the NCP had a strong negative correlation with the winter temperature. Combination of both the NCP and the AO indices improved the correlations in all stations, implying both NCP and AO as major patterns for explaining the winter temperature variability. The results show that the positive NCP was associated with enhanced precipitation and cloudy conditions, consequently causing below normal temperature over Iran. Tabari and Hosseinzadeh Talaee (2018) showed the trend in annual Tmax and Tmin averaged over all 19 stations in central Iran was 0.090 and 0.444 °C per decade, respectively and The Tmax and Tmin warming trends were more obvious in summer and winter than in autumn and spring.

The previous studies related to Hamedan region showed the importance of detection of the possible impact of climate change on water resources (at the regional and local scale) which affect every aspects of the Hamedan societies (INMO 2004, MRO-HP 2006). The overall objective of this research was to reveal spatial and temporal patterns of long-term trends and to detect the possible change points of the Hamedan Province of Iran.

Material and methods

Description of the study area

The area covers a western region of Iran which has a total surface of 19.53×103 km, situated between latitudes 33°59′ to 35°49′N and longitudes 47°34′ to 49°29′E (Figure 1). The area is relatively mountainous range in altitude form 1000 to 3550 m. The mean annual precipitation (total rainfall and snowfall) in the study area is about 350 mm with a range of 280 mm in the central low lands of the region to 550 mm in the mountainous area and has a strong temporal variability. At lower elevations (less than 2500 m) rainfall commonly occur during autumn and winter months. Above this elevation, snowfall occurs during winter, spring and autumn, but rain is also the dominant precipitation of the region. Generally, during April and March, precipitation is often minimal but the rainfall events normally occur with high intensity.

The mean annual air temperature of the region is 11.8 °C and the central and eastern parts of region are characterized by low temperatures and the southern parts by high temperatures. Based on the Emberger climatological classification, the global climates of southern and northern regions are cold semi-arid and very cold arid, respectively (INMO 2004).

Based on the hydrometric stations, more than 25 hydrological catchments (from 29 to 14277 km^2) are identified at the low hills and high elevations of the area. About 50% of the catchments comprise the great basins, which are larger than 1500 km^2. Agricultural activities in the region consist of depression and glacier cultivation. About 80% of the areas are occupied by agricultural lands that have impact on surface water quality of the region. Natural vegetation of the region is relatively zoned by altitude.

Figure 1. Map of area showing the Hamedan Province in Iran

Data selected

In most parts of the western Iran availability of meteorological data both in space and time is limited. In this investigation, five main meteorological stations including Hamedan, Ekbatan Dam, Dargazin, Nojeh and Varayaneh were chosen to provide a broad coverage of the region, with respect to their length of record, homogeneity and geographical distribution (Table 1). The dataset was adjusted for homogeneities at the daily timescale, by taking into account the magnitude of discontinuities for different parts of the distribution. Stations records extend mostly from 1970, when digitised daily records are generally available in the Iranian National Climate Centre's database, through to 2010 (INMO 2004). Herein, the observed daily data of the stations that maintained long-term records of annual temperature including main temperature from 1980 to 2010, in the Hamedan Province, were used for detection of exiting trends of the time series.

A series of statistical tests was applied to check the stations data integrity further, using SPSS (1999). Missing data (in each station) were about 2% of all the observed period. They were replaced by a simple approach consisting of a regression method.

Table 1. Information of the meteorological stations

Station	Type	Geographical characteristics		
		Elevation (m)	Latitude	Longitude
Hamedan	Synoptic	1730	34°52′	48°32′
Nojeh	Synoptic	1679	35°12′	48°41′
Ekbatan Dam	Meteorological	1880	34°46′	48°36′
Dargazin	Climatologic	1870	35°21′	48°04′
Varayaneh	Meteorological	1800	34°05′	48°24′

Data Analysis

Several tests are available for the detection or quantification of trends. In this study, time series of annual temperatures of the selected stations were investigated based on the Mann-Kendall and Normalizes Residual Mass Curve (NRMC) methods to detect the climate change and possible trends of the mean.

The Nonparametric Mann-Kendall method

The Mann-Kendall method which is a rank correlation test is used to detect possible trends in data series and to test trend significance (Sneyers 1990). A detailed assessment for testing of climatic data unevenly distributed in time and a comparison of methods for estimating the significance level of a trend can be found in the studies performed by Huth (1999), Yue & Hashino (2003) and Xu et al. (2004). The Mann-Kendall's statistic u(t) is a value that indicates direction (or sign) and statistical magnitude of the trend is a series.

When the value of u(t) is significant at the 5% significance level, it can be decided whether it is an increasing or a decreasing trend depending on whether $u(t)>0$ or $u(t)<0$. A 1% level of significance was also taken into consideration. Partial and short-period trends and a change point or beginning point of a trend in climatic series were investigated by using time-series plot of the $u(t_i)$ and $u'(t_i)$ values. In order to obtain such a time-series plot sequential values of the statistics u(t) and u'(t) were computed from the progressive analysis of the Mann-Kendall test. This procedure is formulated as follows (Sneyers 1990):

First, original observations are replaced by their corresponding ranks y_i (i=1, 2, … , n-1), which are arranged in ascending order. Then, for each term y_i, the number n_k of terms y_j preceding it (i>j) is calculated with ($y_i>y_j$), and the test statistic t_i is written as:

$$t_i = \sum_{k=1}^{i} n_k \tag{1}$$

The distribution function of the test statistic t_i has a mean and a variance derived by:

$$E(t_i) = i(i-1)/4 \quad (2)$$

$$Var(t_i) = [i(i-1)(2i+5)]/72 \quad (3)$$

The values of the statistic u(t$_i$) are then computed as:

$$u(t_i) = [t_i - E(t_i)]/\sqrt{Var(t_i)} \quad (4)$$

Finally, the values of u'(t$_i$) are similarly computed backward, starting from the end of the series. With a trend, intersection of these curves enables the beginning of a trend in the series to be located approximately. Without any trend a time-series plot of the values u (t$_i$) and u'(t$_i$) shows curves that overlap several times.

The Normalized Residual Mass Curve Method

The Normalized Residual Mass Curve Method is a graphical representation of data to show the current temperature or precipitation changes (Milly 2003, Tosic & Unkasevic, 2005, Green et al. 2007). In this study, the three following steps of calculation were considered. In the first step, three primary descriptive parameters including: i) raw observations, smoothed values that enhance the systematic variations of data, ii) fluctuating component which detects the small period variations of data and iii) moving averages that reveals the long period variations of data were graphically displayed. In the second step, four secondary descriptive parameters including: trends, cyclic (yearly), seasonal and irregular components were calculated. Finally, the Normalizes Residual Mass Curve method was applied to enhance the current temperature changes. The NRMC method could be concluded using below equation:

$$NRMC_{Trm} = \frac{Sum\lfloor NRMC_{Tr_{n-1}} + (T_{i_n} - T_m)\rfloor}{T_m} \quad (5)$$

In which, T_m and T_{in} are the long term average and yearly observed data, respectively. The $NRMC_{Trn}$ and $NRMC_{Trn-1}$ are the normalised residual mass curve during the first and one year before the end year of data, respectively. The $NRMC_{Tr0}$ is equal to 0.

Results

Similar results were achieved for the Mann-Kendall and the NRMC methods. Table 2 and Figure 2 present the results of Mann-Kendall tests for mean annual temperatures, respectively. Figure 3 also show the results of NRMC method of the same data.

The mean annual temperature of all the stations presented a significant increasing trend, except those of Varayaneh and Darghazin stations (Figure 2 and 3).

The results of this study indicated that annual temperatures had a warming trend.

Table 2. The values for u(t) and trends for the Mean temperature parameter

Station	u(t)	trend
Hamedan	0.31	1.61
Nojeh	0.42	1.17
Ekbatan Dam	1.4	1.67
Darghazin	-0.13	1.1
Varayaneh	-0.53	0.28

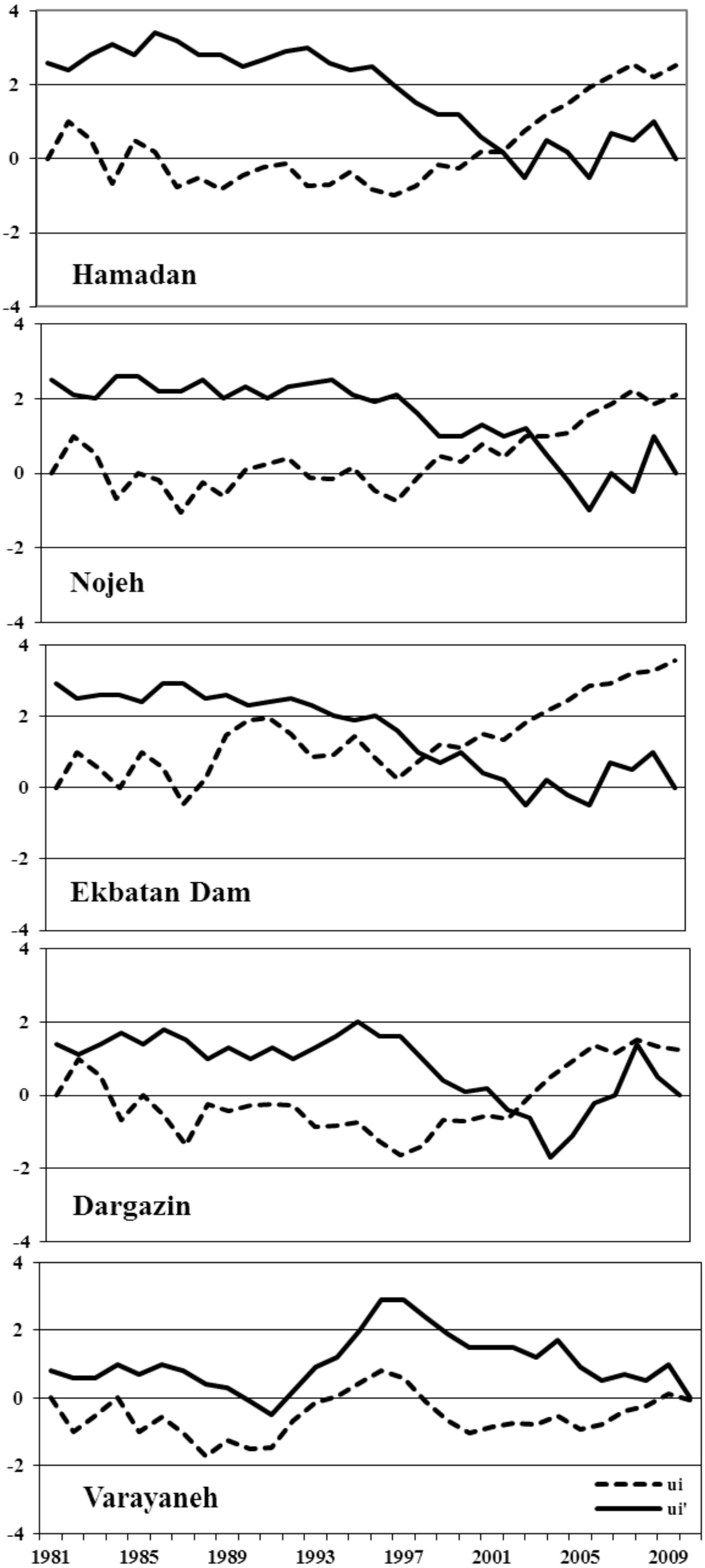

Figure 2. Mann Kendall statistics $u(t_i)$ and $u'(t_i)$- Mean temperature

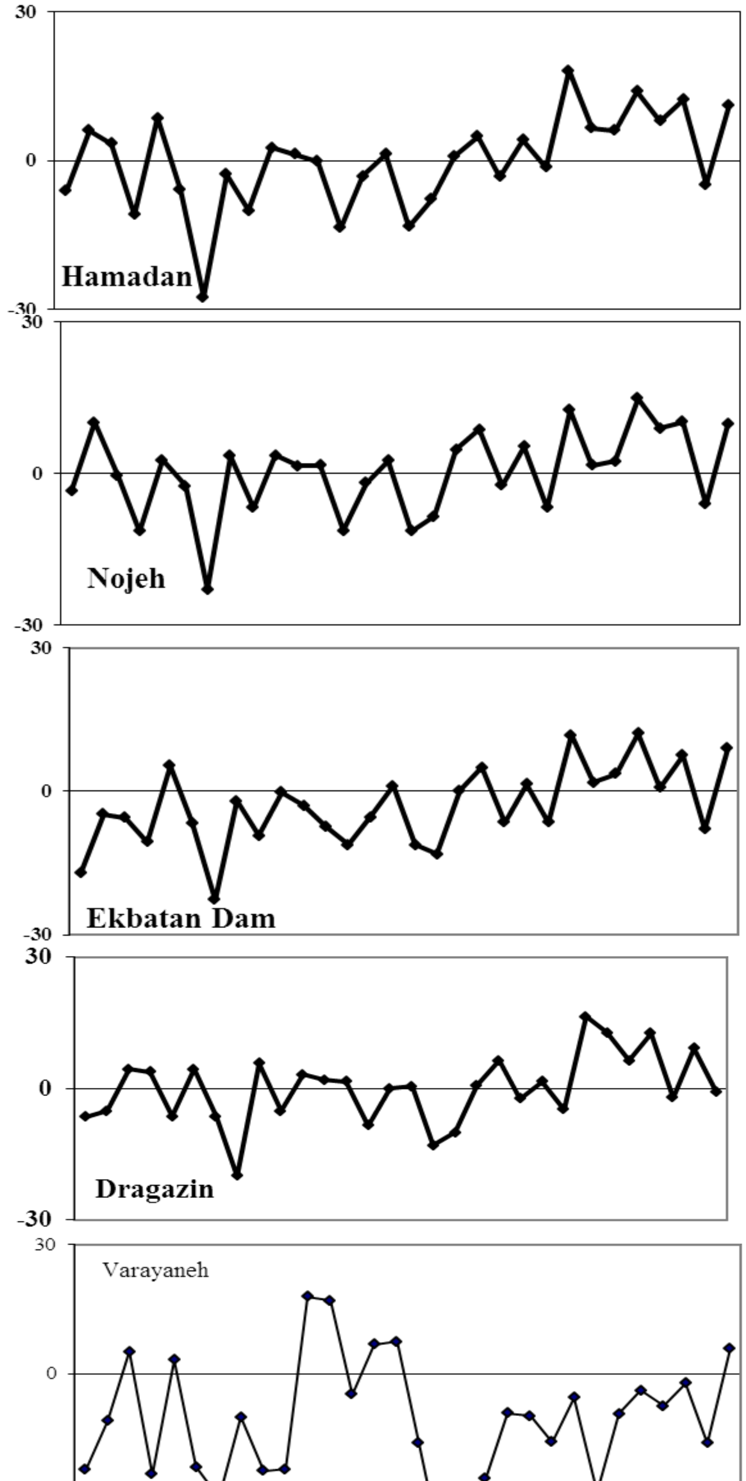

Figure 3. NRMC statistics-Mean temperatures

Discussion and Conclusion

This study not only illustrated the similar results of the two different tests on climate change identification (the Mann-Kendall and NRMC methods), but also a significant warming in the majority of stations in the region (especially at the central part). Similar results were shown by De Luis et al. (2000), Ahrens (2006) and Silva et al. (2006) in other countries.

Using another climatologic data (such as precipitation or relative humidity) or other dataset periods could be effective to verify the homogeneity of results of the Mann-Kendall and NRMC methods.

The spatial variation of temperature changes of the region was another result of this study. Relatively, Varayaneh and Darghazin stations showed they had different trends to others. These results provide useful information for long term planning in water management of the region. To present the complexity of climate of the region and to show the trends and anomalies of air temperature variations, more complementary detailed investigations are necessary.

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