

Spatial and Temporal Trend Analysis of Temperature and Precipitation in Iran

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ABSTRACT Analysis of the spatial and temporal trends of precipitation and temperature are pertinent for future development and sustainable management of water resources in a given region. In this paper, we present a study concerning the climatic behavior of two principal observables Variables, viz. monthly temperature (maximum and minimum) and mean precipitations obtained from the measurements carried out in 60 Iranian meteorological stations for 40 years from 1969 to 2008. The Mann-Kendall test was used to detect the significant trends. Results showed that during summer and autumn, the precipitation had a negative trend (at 5% significant level) in the south-eastern parts of Iran and this trend is less during spring, but no special trend was observed in winter. The minimum and the maximum temperatures did not have any particular trend in winter. Spring was accompanied by an increase in positive trend in the maximum temperatures in the south-west and north-east, while the minimum temperature only limited in the south-west parts. Positive and negative trends of the minimum temperature were very dispersed during the summer. The maximum temperatures had a negative trend in the north-west and no positive trend was observed at 5% significant level. During autumn, the temperatures indices had positive and negative trends with a wide range of dispersion.

Key words: *Climate change, Climatic variables, Iran, Mann-Kendall, Spatial distribution*

1 INTRODUCTION

Global rising temperatures since the last century have caused concern among societies and governments all over the world about climate warming and environmental changes (IPCC 2007; Holland *et al.*, 2006; Qin, 2005). The trends in temperature and precipitation as two of the most important indicators of climate change have become hot topics (Yang *et al.*, 2012). Various studies were carried out in different parts of the world for detecting

possible climate trends and changes. Results show significant trends, especially during the last four decades (Bani-Domi, 2006). Climatic change is one of the most important issues at the present time. Analyzing and discovering historical changes in climatic system are one of the most important requirements in climate change study (IPCC, 1996). In the current years, several researchers studied variability and trends in precipitation throughout the world (Bocheva *et al.*, 2009; Zhang *et al.*, 2009;

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Huang, *et al.*, 2009; Krishnakumar *et al.*, 2009; Casa and Nasello, 2010; de Luis *et al.*, 2010; Qin *et al.*, 2010; Xu *et al.*, 2010; Caloiero *et al.*, 2011; Li *et al.*, 2011; Subash *et al.*, 2011; 2011).

A recent global climate change assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) declared that surface temperatures, expressed as global average, increased about 0.74°C over the last hundred years (IPCC 2001, 2007). The global average temperature is currently 15°C. Geological and other evidences suggest that, in the past, this average could be as high as 27°C and as low as 7°C (Frei and Gassner, 2008).

In addition, observations show that changes are occurring in the amount, intensity, frequency and type of precipitation with an evidence of intensification of the global water cycle (Huntington, 2006). Moreover, Precipitation is one of the most important variables in the global hydrological cycle of meteorology and climate (Prigent, 2010).

Concerning the climate of Iran, several studies have been performed (Rostamian, H, 2001; Alijani and Ghavidel, 2005; Azizi, G. and Roushani, 2008; Hajam *et al.*, 2008) to investigate temperature and precipitation trends. These studies pointed out significant variations in climate of Iran.

For example, Modarres and da Silva (2007) examined the time series of annual rainfall to assess climate variability in the arid and semi-arid regions of Iran. Results indicated that increasing and decreasing monthly rainfall trends over large continuous areas in the study region. These trends were statistically significant during the winter and spring seasons, suggesting a seasonal movement of rainfall concentration.

Zohrabi *et al.* (2014) showed that the range of natural climate variables for temperature and precipitation changes (95% probability) are less than 1.8°C and 40%, respectively in the west part of the northwest of Iran.

Tabari and Marofi (2011) studied temporal variations in pan evaporation (E_{pan}) and the associated changes in climatic variables in western Iran for the period of 1982–2003. Their results showed a significant increasing trend in E_{pan} at 67% of the selected stations, and the increasing E_{pan} was strongly related to air temperature changes. Tabari *et al.* (2011) analyzed the trends in annual, seasonal and monthly reference evapotranspiration (ET_o) in the western Iran during 1966–2005. They showed a positive trend in ET_o at the majority of stations. In addition, the main cause of the increasing trend in ET_o was an increase in air temperature in the study area.

Since the studies related to climatic change in Iran are new and due to the vast area of this country, majority of the performed investigations are single-sample (station) and rarely any studies were carried out in the field of climatic change research in an extensive scale in the country (Alijani and Ghavidel, 2005). Hence, regional studies about the country's climatic change in an extensive scale should be considered.

In spite of that several efforts made to examine the precipitation and temperature trends in Iran during the last decades, no comprehensive research was conducted to determine the precipitation and temperature trend in this large scale (whole parts of Iran) by the Mann–Kendall rank statistic test. For these reasons, in this study we performed a regional trend analysis of Iran temperature and precipitation in the period of 1969–2008.

2 METHOD AND MATERIALS

Monthly precipitation and temperature time series are available on the website of Iran meteorological organization (<http://www.weather.ir/farsi/>). Sixty meteorological stations were analyzed for the period from 1969 to 2008. Figure 1 shows the situation of weather stations on Iran map. Missing data are then generated using the kriging

interpolation technique. Trend significance was analyzed using the non-parametric Mann-Kendall test (MK) at significance level of 0.5. One of the most important problems and difficulties existed in present research was the lack of long-term statistics (data) for many of the stations present in Iran. According to the existing statistics (data), there are more than 600 stations in Iran which hold the responsibility of recording data (<http://www.weather.ir/farsi/>), but unfortunately, only 60 stations have long-term data; however, and these station have 40 years data approximately.

A kriging analysis was used for spatial interpolation. This method, while computationally intensive, is a true interpolation technique and is found to be the optimal scheme for irregularly spaced point climate data (Collins and Bolstad, 1996; Goodale *et al.*, 1998; Boyles and Raman, 2003). In temperature and precipitation analyses, a universal linear kriging interpolation scheme

with a minimum sample of 12 points was used. This technique was used instead of other methods because it allows an interpolation without the need of repeatedly analyzing the structure of semi variograms (Boyles and Raman, 2003).

2.2 Mann-Kendall test (MK)

The MK test (Mann, 1945; Kendall, 1975) is one of the widely used non-parametric tests to detect trend significance in time series (Kahya and Kalayci, 2004; Brunetti *et al.*, 2005; Bani-Domi, 2006; Cannarozzo, 2006; Partal and Kahya 2006; McBean and Bartholy and Pongr acz, 2007; Motiee, 2008; Hamed, 2008) for hydrological and climate analysis. This test used by many researchers and was found to be an effective tool for identifying trends in hydrologic and other related variables (Hirsch *et al.*, 1982; Burn, 1994; Burn and Hag Elnur, 2002, Yu *et al.*, 2002).

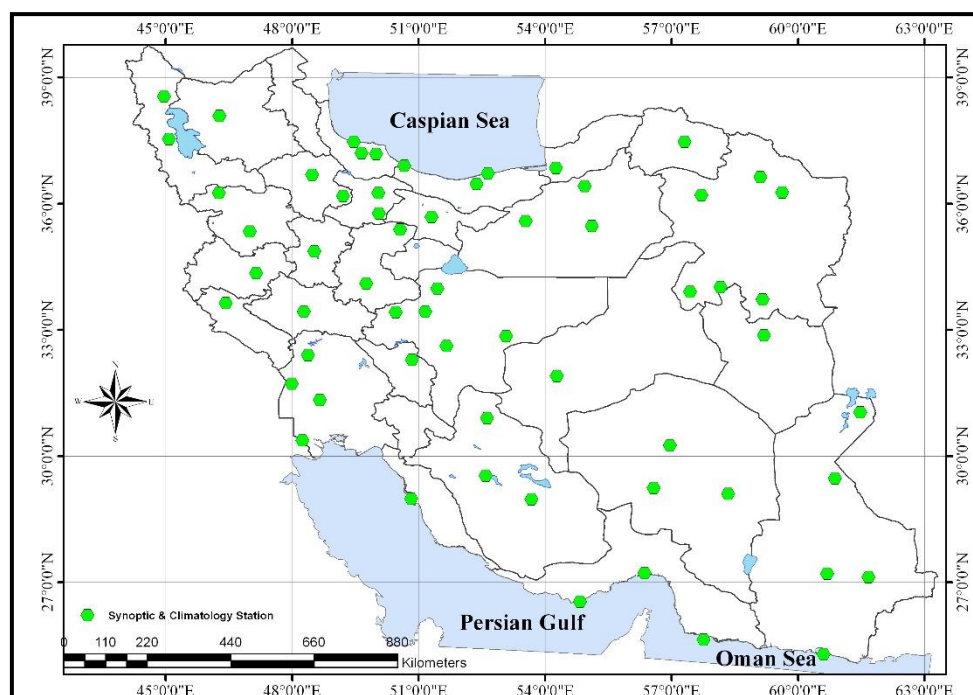


Figure 1 Location of Synoptic and Climatology Station

The MK rank test was proved to be useful for detecting a linear trend in the data. Assuming x_1, x_2, \dots, x_n to be the time series data. P refers to the number of pairs (i, j) where $x_j > x_i; j > i, j=1, \dots, n$ (the number of each elements) and $i=1, \dots, n-1$. The mean and variance are given by (Brockwell and Davis, 1991):

$$E(t) = n(n-1)4^{-1} \quad (1)$$

and its variance equals:

$$\text{Variance}(t) = [n(n-1)(2n+5)]72^{-1} \quad (2)$$

MK rank statistics (t) to confirm the significance of the observed trend. The value of t can be used as the basis of a significant test by comparing it with:

$$(T)_t = \pm t_g \sqrt{\frac{4N+10}{9N(N-1)}} \quad (3)$$

where as t_g is the desired probability point of the Gaussian normal distribution. In the present study, t_g at 0.01 and 0.05 points has been taken for comparison. Apart from this, the linear trend fitted to the data was also tested with t -test to verify results obtained by the MK test. In order to obtain $U(t)$, the following equation is utilized (Bani-Domi, 2006):

$$U(t_i) = [t_i - E(t_i)] (\sqrt{\text{Var}(t_i)})^{-1} \quad (4)$$

When increasing or decreasing trend is observed in $U(t)$ value, it is significant. As a result $u(t) > 0$ or $u(t) < 0$ is gained. t_i value which equals sum of n_i and t_i which is the sum of n'_i are given in 7th and 8th columns respectively, and $E(t)$ and Variance values are given in 9th and 10th columns.

While analysis of seasonal observations from each station provides insight into the

climatic trends for those specific locations, a single station cannot be used to represent the entire climatic region. Using GIS, climatic trends from each station can be spatially analyzed, providing an accurate picture of regional climatic trends.

3 RESULTS AND DISCUSSION

In order to identify the existence of changes or trends in time series in the selected stations, MK test was utilized. Through T statistics analysis and T critical statistics, Mann-Kendall test was determinate. With the purpose of providing a complete behavior of temperature and precipitation variations both in space and time, we analyzed the monthly climate seasonal averages for each station.

3.1 Precipitation

Iran is an arid zone with very low atmospheric fall. Average annual fall in arid land of the world (estimated to be about 860 mm (Alizadeh, 2007)) is compared with average annual fall of Iran (approximately 250 mm) it can be observed that the average fall in Iran is even less than one third of the average fall of the world.

Moreover, time of atmospheric fall and their location do not conform to the needs of agriculture section, which is known as the main water consumer in the country. Therefore, it must be accepted that aridity is a climatic reality in Iran and in order to live in an arid place, the resort (solution) is to recognize the climate and to adjust to it but not to confront it (Alizadeh, 2007). This research studied the trend of fall changes during 1969-2008 by using MK test.

Monthly records were summed to provide seasonal and annual totals of each year. Seasonal and annual time series were then statistically analyzed and fitted with MK test. Results obtained using MK test in winter for fall

parameter showed that low changes in the data trend during the statistical period. Noteworthy point during this season, fall is decreasing in the northwest and increasing in the southwest of Iran (Hazbavi *et al.*, 2013). In the northwest, Khoy station had a negative trend and had influenced the negative trend of fall of this region of the country. A positive fall trend was seen in the south and southwest of Zagros mountain chain. It must be mentioned that in winter spatial trend analysis rainfall have most annual fall in the most parts of Iran. According to the obtained results it can be observed that not much changes have occurred in the fall trend during this season. However, it is noticeable that fall increasing, was not significant in the country's southwest parts. Figure 2 shows the precipitation trend for winter during the statistical period of 1969-2008.

The spring fall especially in the southern and eastern parts of Iran has had a decreasing trend so that most changes occurred in the southeast of Iran, and the fall occurred in the spring season (Figure 3). This reduction is significant in the level of 0.5 and 01%. No special trend was observed in the country's western and northwestern parts. Results specified that this part of the country has had a positive trend during spring and fall trend have been increased in this season. Although no significant trend was observed in these areas, in this context more researches must determine its cause and quality in future. Figure 3 demonstrates the fall trend for spring season during the statistical period of 1969-2008.

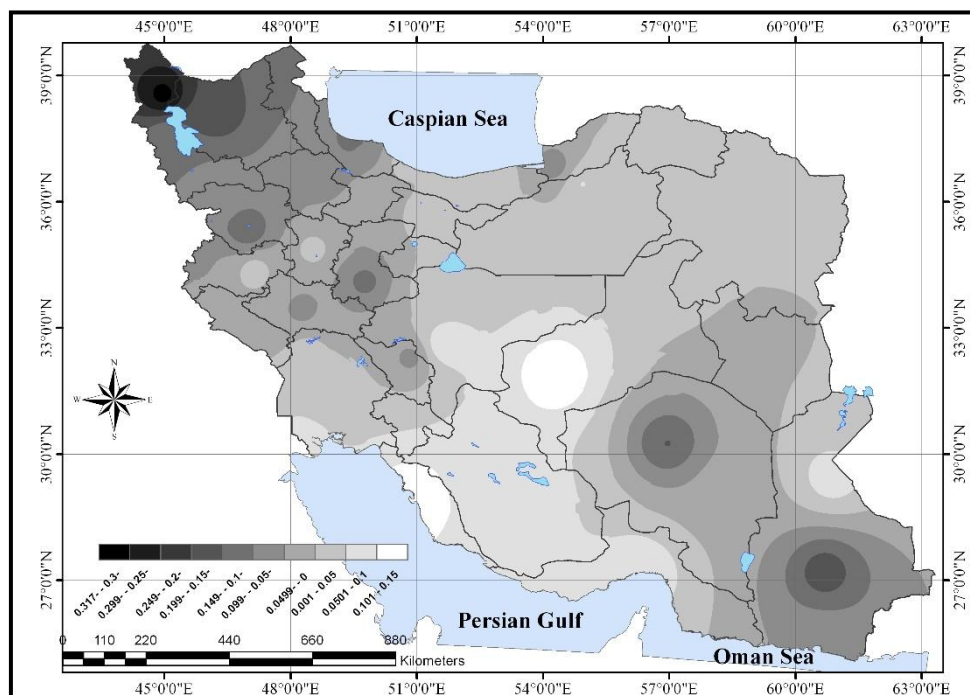


Figure 2 Precipitation trends for the winter season over the period 1969-2008

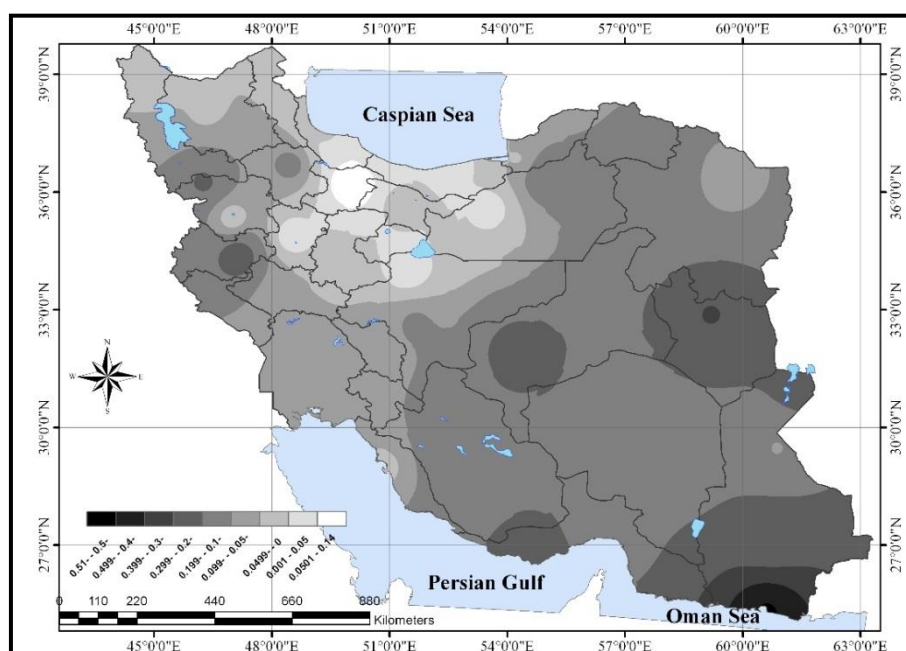


Figure 3 Precipitation trends for the spring season over the period 1963-2008

During the warm period of the year (summer), due to the constant subsidence of the weather in the south and under subtropical jet stream, subtropical high-pressure is formed. High-pressure state which controls the Iran climate is located on Azoor islands and during the summer, it is extended in a blaze form through Mediterranean Sea above the Middle-East including Iran and dominates all parts of Iran in the south of Alborz Mountains (Alijani, 2002). The results of this study showed that fall changes in the south of Alborz Mountains to the southeast of the country follow a negative trend and this trend is heavier in the southwest and south of the country. In other words, during the study period, according to the results of MK test, decreasing trend of fall in these regions is significant in the level of 0.1% percent. Yet, in the north of the Alborz Mountain range the change trend has been much more different with its southern parts. So, this trend especially in coast of Caspian Sea causes the fall in the area to be increased. This increase is not significant at the level of 5 % significant level. Figure 4 shows fall trend for summer during the statistical period of 1969-2008.

According to the Iran climate, with the beginning of the cold period of the year, fall rate increases throughout Iran and the big amount of Iran's fall occurs in the south of Caspian Sea. The trend observed in autumn is just like winter, but it has some differences regarding the extensiveness of the positive and negative trends. During this season, a negative trend is observed in the southeast parts, which indicates the reduction of autumn fall in this part of the country during the investigated period. This trend is significant in the sig. level of 0.5 percent. It can be stated that the increasing changes was not significant in any part of Iran (Figure 5).

Based on the spatial analysis of seasonal trend, a few general conclusions can be made about precipitation trends over the study period. The winter shows no general spatial trend in precipitation, while the summer season shows widespread decreases. The spring shows an increasing trend in the south of Caspian Sea and decreasing trend in the center and south of Iran. The fall season showed an increasing precipitation in most regions of Iran especially in the north.

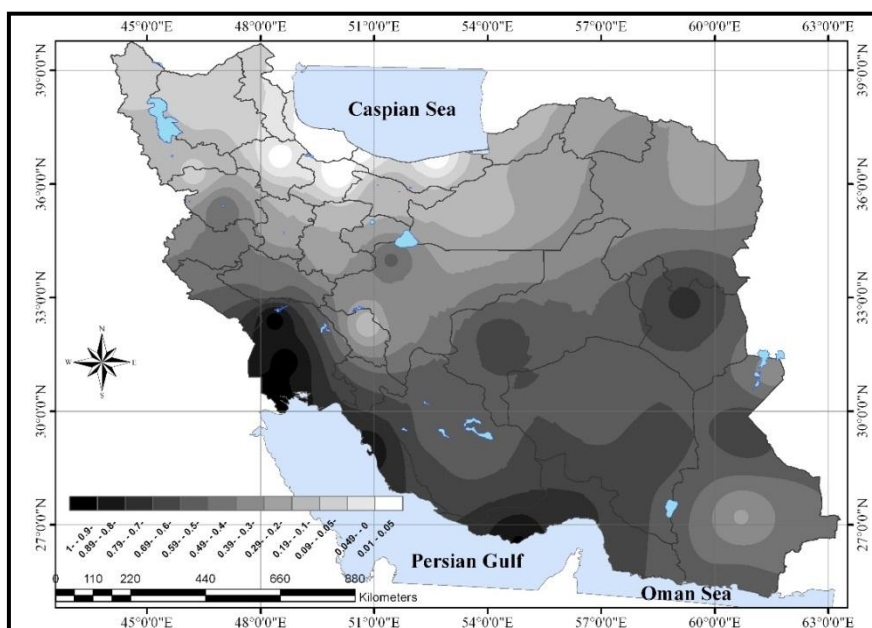


Figure 4 Precipitation trends for the summer season over the period 1969-2008

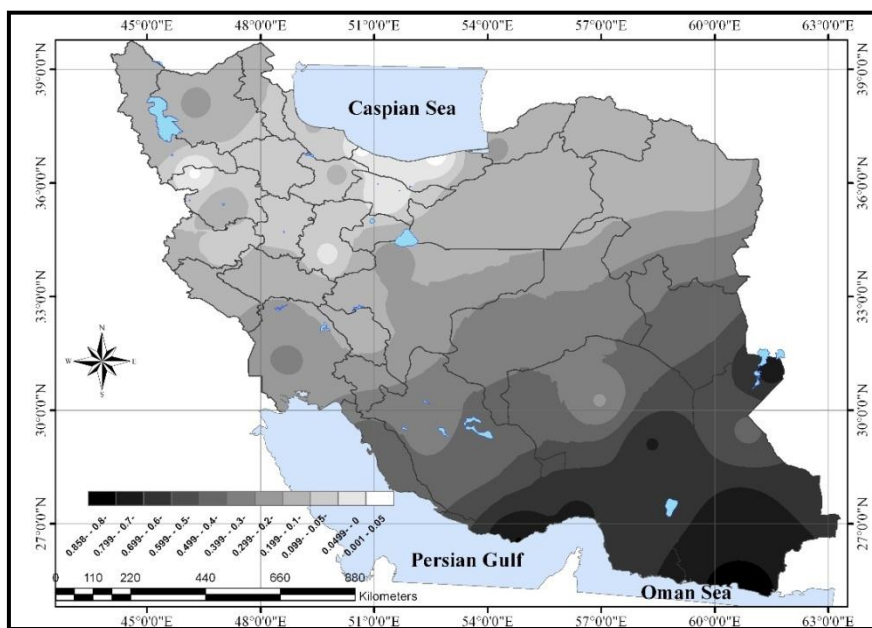


Figure 5 Precipitation trends for the autumn season over the period 1969-2008

3.2 Temperature

3.2.1 Minimum temperature

Detection and prediction of long-term changes in temperature patterns are often the driving force in climate change analysis. In analysis use of mean

temperature alone can hide significant patterns in temperature. In the present study, the minimum and the maximum temperature was used also for trend analysis.

The minimum temperature trend is shown in Figure 6. In most regions of Iran, no significant trend was observed. Minimum temperature was decreased in the south and east. Also a

temperature increasing can be mentioned in the north-east parts of Iran. These changes have a significant level of 5 % significant level.

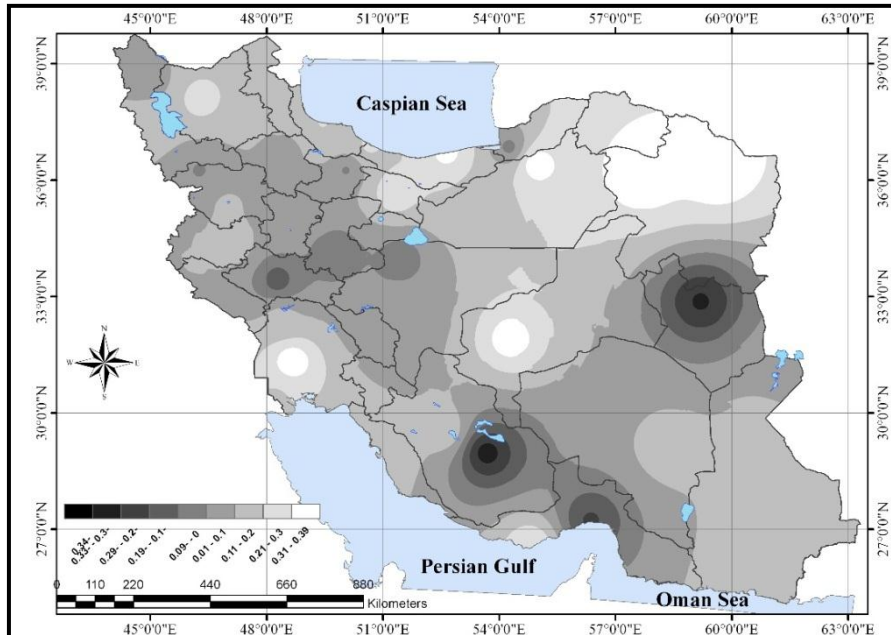


Figure 6 Minimum temperature trends for the winter season over the period 1969-2008

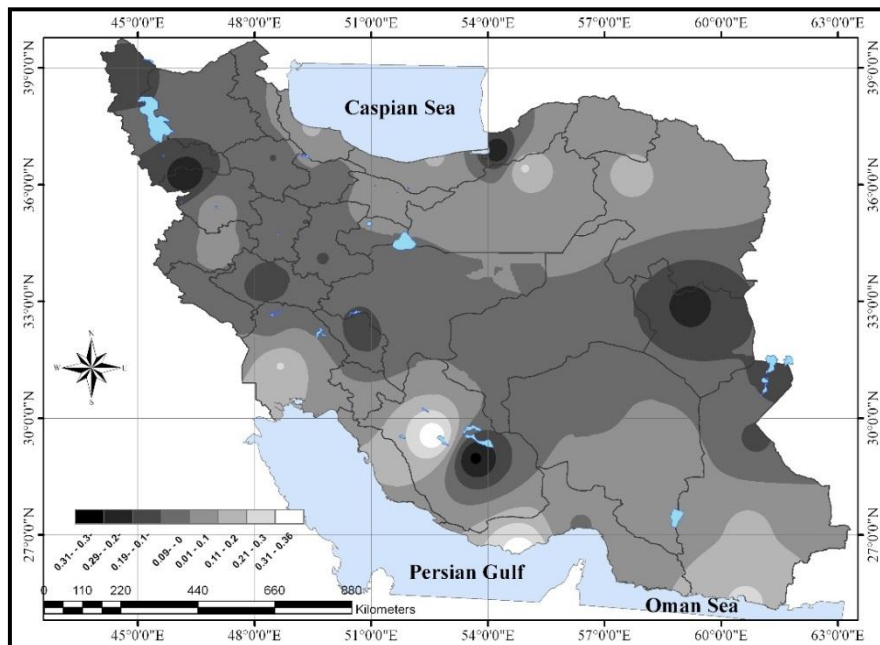


Figure 7 Minimum temperature trends for the spring season over the period 1969-2008

Figure 7 shows the spatial trend MK Test of minimum temperature for the spring season. Also, trend in the southwestern of Iran was positive but generally can be say that in all regions there are a negative trend in a scattered way. In other regions of Iran, no specific trend was observed in the minimum temperature.

The minimum summer temperature did not had much differences compared to spring season.

In this season, the positive trend increased and these types of trends observed in the northeast and southwest parts, while negative trends has been seen as stains in the south and northwest. Both trends are significant in the sig. level 5 % significant level. Figure 8 shows the trend of minimum temperature in the summer season in Iran during the investigated period.

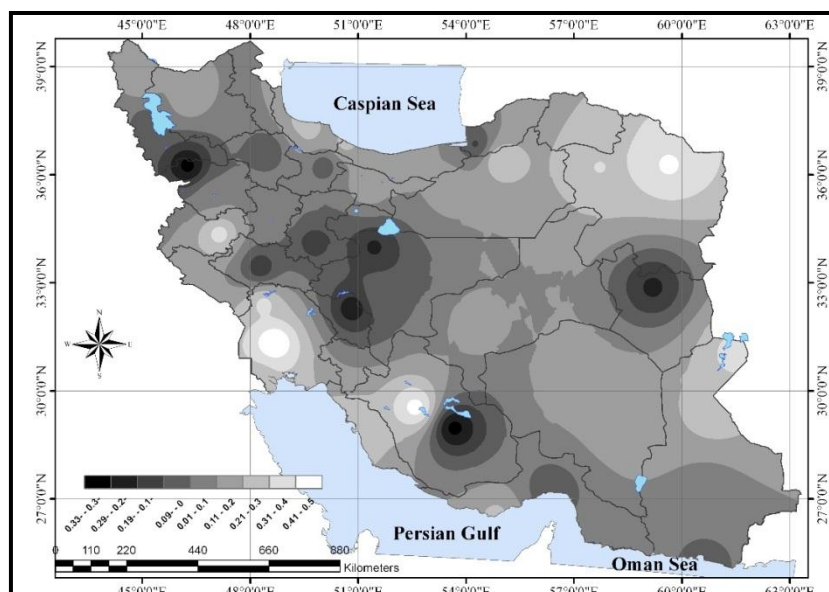


Figure 8 Minimum temperature trends for the summer season over the period 1969-2008

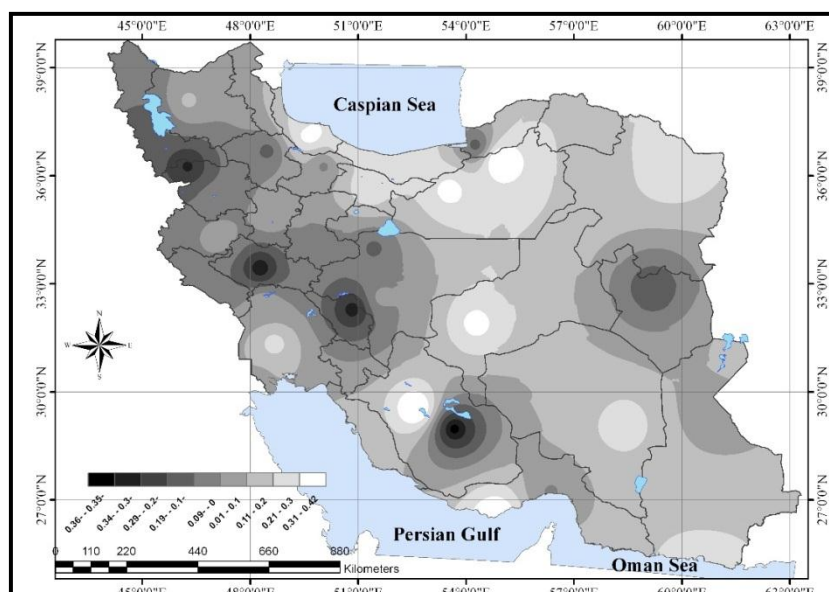


Figure 9 Minimum temperature trends for the autumn season over the period 1969-2008

One of the interesting points about minimum temperatures in Iran autumns is an increase in the dispersion of negative and positive trends in this season. It can be observed in Figure 9 that positive trends include some parts of the northeast, south of Caspian Sea and southwest of Iran, while the negative trends are expanded in the northwest, west, and east of Iran.

3.4 Maximum temperature

Figure 10 shows the maximum temperature during winter in Iran. It can be observed from analysis that there was significant trend during this season of the year. But negative trends only observed in the southern and coastal parts of the country. An increasing trend of maximum temperature was not significant in northwest of Iran.

During spring, many differences can be observed regarding the maximum temperature trend. So that the most parts of Iran was

consisted of maximum temperature without any trend.

Figure 11 shows that northeast, west, and southeast parts had a positive trend and no negative trend could be observed during this season of the year.

The trend of maximum temperature is shown in Figure 12. It can be observed from Figure 12 that the northwest and central parts of Iran had a negative trend in a sig. level of 0.5% and the other parts were without any trend.

Trend of changes in the maximum temperature in autumn during the study period in Iran can be divided into two areas: areas with positive trend and areas without any trend. Areas with a positive trend can be observed in northwest, northeast, and west of Iran and other parts did not follow a specific trend in the maximum temperature during autumns (Figure 13).

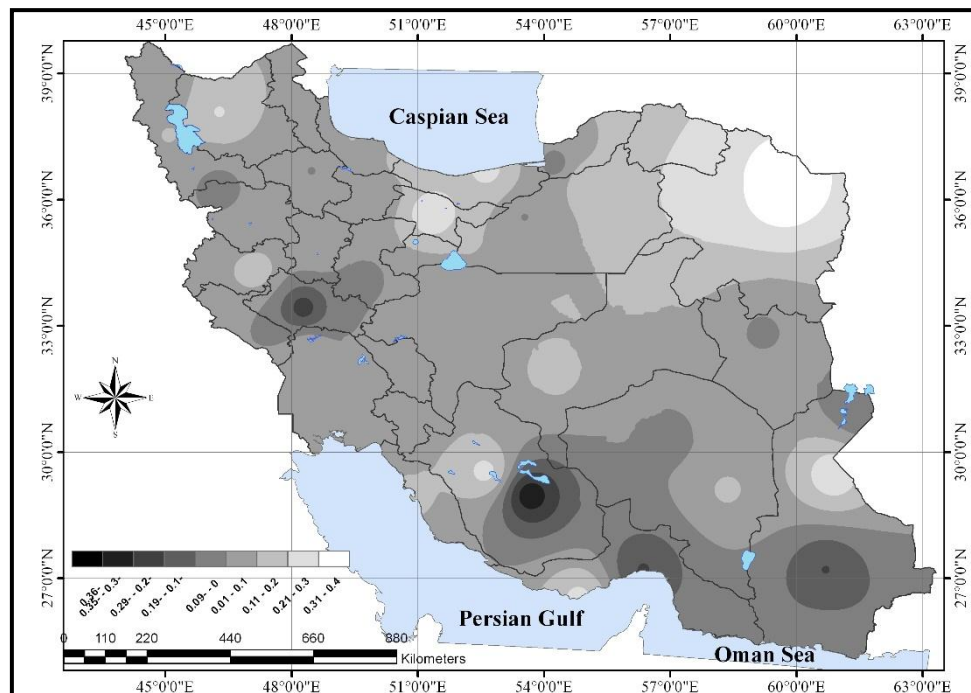


Figure 10 Maximum temperature trends for the winter season over the period 1969-2008

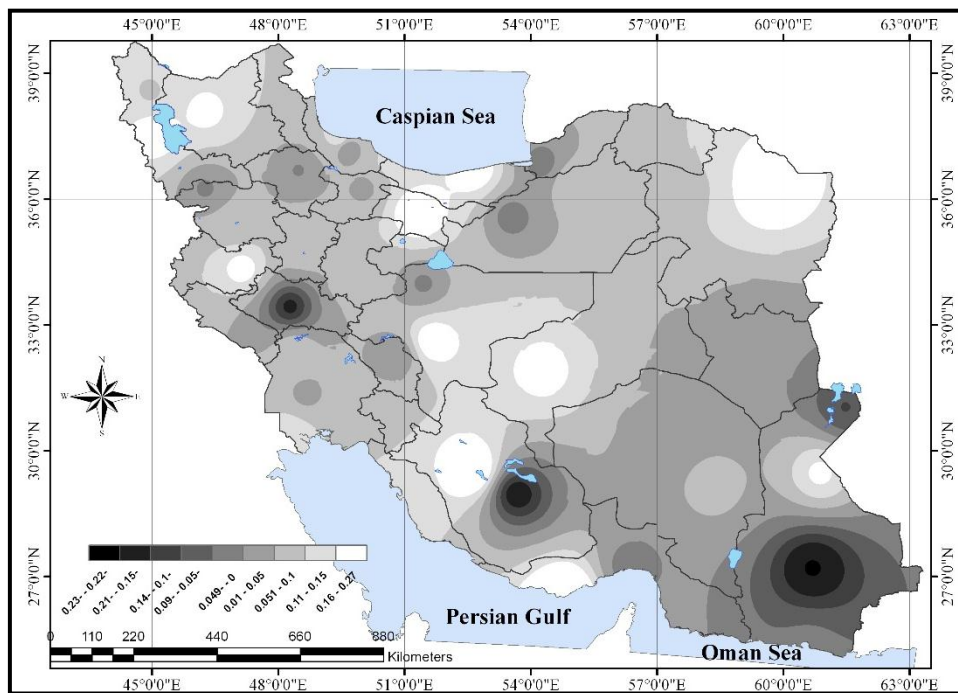


Figure 11 Maximum temperature trends for the spring season over the period 1969-2008

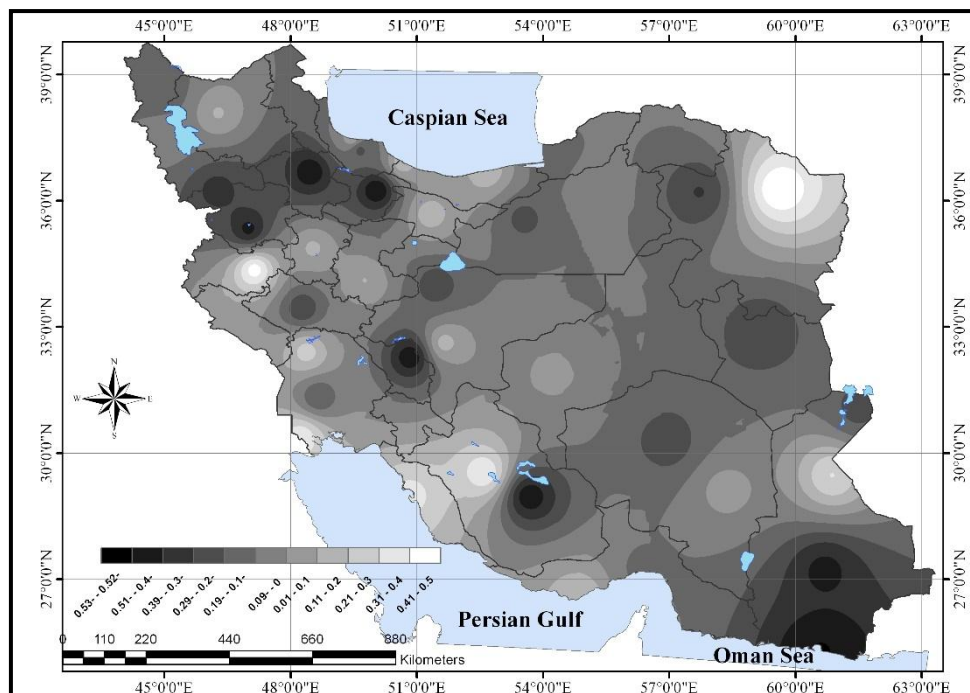


Figure 12 Maximum temperature trends for the summer season over the period 1969-2008

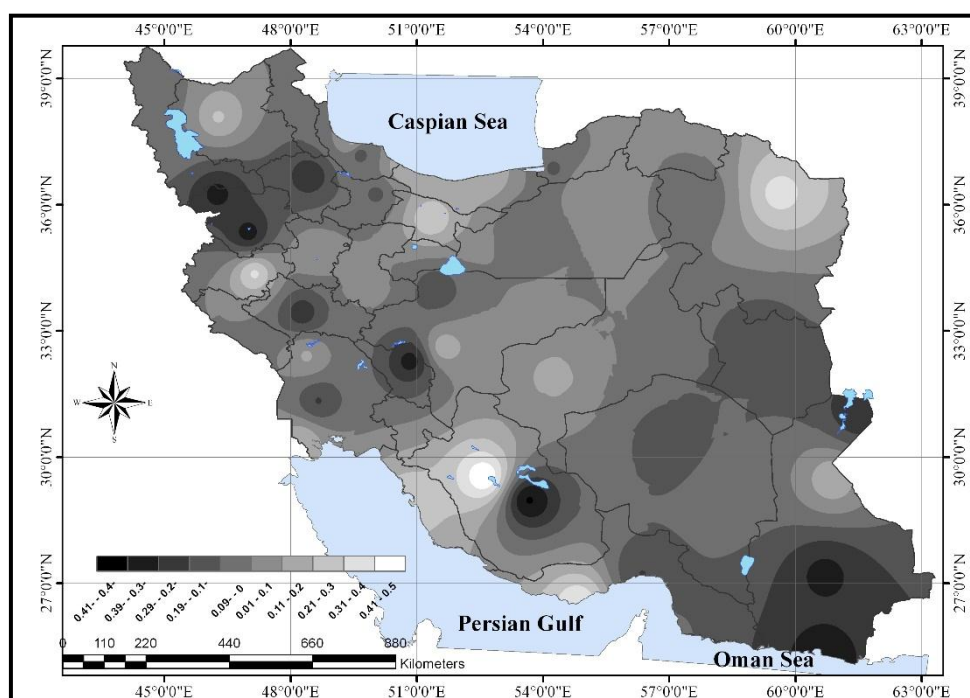


Figure 13 Maximum temperature trends for the autumn season over the period 1969-2008

4 CONCLUSION

The trends of the seasonal precipitation and temperature time series were analyzed with the MK test for 60 stations in the whole of Iran during 1969-2008.

Results of the present research indicated that temperature and precipitation changes enumerate most important climate characteristics of Iran which have been occurred during the past years. However temporal and spatial distribution, intensity and weakness, have not happened similarly throughout of Iran, but it has faced many spatial changes such as the climatic spatial changes in Iran.

The spatial calculations of the trends showed that no identical system exists in the country, but there was no special trend in most parts of Iran and only a few parts of the country have a positive or negative trend. Tabari and Marofi (2011) showed that the variations of the precipitation series were not uniform over the region and there were various patterns (increasing and decreasing trends). According to the obtained results, the

seasonal precipitations trend was negative in most times of the year. This condition was extremely observed in summer and autumn especially at southeast and center of Iran. Zohrabi *et al.* (2014) confirmed that there was a decreasing trend over 1968 to 2008 in most rain gauge stations. Due to the fact that with temperature increasing, the increase in precipitations rate is also expectable, but in arid regions such as Iran negative trends of precipitation occur as what observed in this present research. The main reason can be accounted by the geographical location of Iran and its being located in an arid and semi-arid areas. There was no humidity in these areas or synoptic factors inhibit the ascending and density especially in the southern and southeastern parts. Thus, according to the increase of humidity capacity, temperature increasing cause the precipitation to be decreased.

Minimum and maximum temperatures do not have a specific trend in winter. Spring have faced positive trend maximum in the southwest and northeast, while the minimum temperatures have

had such a trend limited in the southwest parts. Maximum temperatures had a negative trend in the northwest and no positive trend was observed in the sig. level of 5 % significant level. All temperature indexes have had positive and negative trend with much dispersion in autumn. Moreover, in this study, significant warming trends in the T_{\min} series were larger than those in the T_{\max} that are in accordance with the results of Tabari *et al.* (2011) and Turkes and Sumer (2004) also reported that trend magnitude of T_{\min} was greater than that for T_{\max} series in Turkey.

According to the global warming, the increase in positive trends can be accounted in temperature indexes. The increasing trend in air temperature have been related to several factors such as global warming, increased concentrations of anthropogenic greenhouse gases, aerosols which exert cooling effects on the climate, increased cloud cover and urbanization (Smadi, 2006). Overall, the increase of air temperature in the study area will increase dry conditions in the region by increasing potential evapotranspiration and consequently places it in serious risk of desertification.

But, more investigations need to justify the reason of being negative and reason of these trends. In addition, Azizi and Roushan (2008) that noted there was a negative trend in maximum temperature of the stations in the south of Caspian Sea, located on the present study, no particular trend was observed in maximum temperature in these regions. But their results about the minimum temperatures, was similar to Rostamian's findings. In addition, Rostamian's findings (1998) about fall reduction in the east of Caspian Sea has been confirmed in present study.

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بررسی روند زمانی و مکانی دما و بارش در ایران

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چکیده دستیابی به مدیریت بهینه در زمینه توسعه پایدار منابع آبی، نیازمند بررسی روند زمانی و مکانی دما و بارش است. در این تحقیق به بررسی رفتارهای دو متغیر اصلی آب و هوا، دمای ماهانه (حداقل و حداکثر) و میانگین بارش در ۶۰ ایستگاه هواشناسی در طی یک دوره ۴۰ ساله از ۱۹۹۶-۲۰۰۸ ساله پرداخته شد. آزمون من-کندال (Mann-Kendall) برای بررسی روند متغیر مورد مطالعه مورد استفاده قرار گرفت. نتایج نشان می‌دهد در قسمت‌های جنوب شرقی ایران طی تابستان و پاییز، بارش دارای روندی منفی ($P=5\%$) بوده و در فصل بهار این روند کم‌تر شده است، اما در فصل زمستان روند خاصی مشاهده نشد. دماهای حداکثر و حداقل ماهانه نیز در زمستان روند خاصی را نشان نداد. روند مثبت دماهای حداکثر در فصل بهار در قسمت‌های جنوب غربی و شمال شرقی افزایشی بوده، در حالی که دما حداقل تنها در بخش‌های جنوب غربی محدود شده است. روندهای مثبت و منفی در دما حداکثر در فصل تابستان بسیار متفاوت بود. دما حداکثر دارای روندی منفی در بخش شمال غربی بوده و هیچ روند مثبت معنی‌داری در سطح ۵ درصد در آن مشاهده نشد. در طی پاییز، شاخص‌های دمایی دارای روندهایی مثبت و منفی با پراکنش زیاد بودند.

کلمات کلیدی: ایران، تغییر اقلیم، توزیع فضایی، متغیرهای اقلیمی، من-کندال