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The Spatio-Temporal Variability of Extreme Temperature Using Gridded AgMERRA Dataset over the Bakhtegan-Maharloo Basin, Iran

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Authors
Jowkar L.[1] *MSc,*
Panahi F.*[1] *PhD,*
Sadatinejad S.J.[2] *PhD,*
Shakiba A.[3] *PhD*

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[1]Department of Desert Sciences Engineering, Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran
[2]Department of Renewable Energy and the Environment, Faculty of New Sciences and Technologies, Tehran University, Tehran, Iran
[3]"Department of Remote Sensing and GIS, Faculty of Earth Science" and "Center for Remote Sensing & GIS Research", Shahid Beheshti University, Tehran, Iran

***Correspondence**
Address: Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran. Postal Code: 8731753153.
Phone: +98 (21) 25640718
Fax: +98 (31) 55913222
alabd_fpanahi@yahoo.com

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ABSTRACT

Aim Trend analysis of climatic variables has got a great deal of notice from researchers recently. This study aimed to investigate the Spatio-temporal variability of extreme temperature indices based on the station data and gridded dataset analyses over the Bakhtegan-Maharloo basin in Iran from 1980 to 2010.

Materials & Methods Climatic data related to the Bakhtegan-Maharloo basin was extracted from AgMERRA dataset for the study period (1980-2010) using R software. Daily temperature data were also extracted from the Meteorological Archive of meteorological stations located in the basin during the study period. Warm nights (TN90p), maximum monthly value of daily minimum temperature (TNx), cold nights (TN10p), and cold spell duration indicator (CSDI) indices had been chosen from the indices recommended by the Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) and calculated by RClimDex software package.

Findings The results of AgMERRA and stations data revealed an increasing trend in warm extremes including TN90p and TNx with the trend changes ranging from 0.135 to 0.721 and 0.061 to 0.139, respectively, but a declining trend in cold extremes including TN10p and CSDI with the trend changes ranging from -0.517 to -0.125 and -0.987 to -0.167, respectively.

Conclusion The results of this study may contribute to a better understanding of regional temperature behavior in the study area. The results indicated that the frequency and intensity of cold extremes have declined, though warm extremes increased. Due to the intensive impacts of temperature extremes on human life, it is essential to speculate the effects of these extreme climatic events in future plannings in various sections.

Keywords Climate Change; Temperature; Climate Extremes; AgMERRA Dataset

CITATION LINKS

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Introduction

Global warming and climate change are undoubtedly the principal challenges managers have faced in various sectors in the recent century. However, climate change itself would add to the complexity of this challenge in a not-too-distant future [1]. The long-term annual climate variables averages, especially temperature and precipitation, are generally used as indicators for assessing climate change [2]. Therefore, extreme temperature and precipitation time series analysis helps to understand past and future climatic variability better [3]. In general, the spatial distribution of climate change effects is not homogeneous [4-6]. Shortage in financial sources and difficulties in getting access to some areas has resulted in too little number of stations established and constructed in some regions in the world [7]. So, gridded data or generated meteorological data would be used as an alternative in areas where meteorological data is unavailable [8].

National Aeronautics and Space Administration (NASA) developed a dataset, namely AgMERRA (AgMIP Modern-Era Retrospective analysis for Research and Applications), as an element of the Agricultural Model Intercomparison and Improvement Project (AgMIP) to create a global and homogeneous network in 2014 [9]. AgMERRA provides daily consistent time series of climatic variables (mean, minimum and maximum temperature, precipitation, solar radiation, relative humidity at the time of maximum temperature, and wind speed) required for agricultural models over the 1980-2010 period [10]. The 1980-2010 time period is used as the baseline period for generating climatic scenarios. In recent years, many pieces of research have been carried out on temperature extremes trends and their variability in different parts of the world [11-13]. Considering the high resolution, availability, and continuous coverage of AgMERRA dataset, it can be considered as a promising option for studies such as climate variability [19], yield gap, and food security in which long-term average data is needed [27].

Bakhtegan-Maharloo basin contains one of the largest grasslands in Iran and is an important agricultural and animal husbandry production basis in Iran. Thus, it may be of great importance in terms of global warming. The decline in water tables, grassland degradation, and land desertification are closely related to climate change. In general, the results of daily climate extremes variability evaluation in Iran have revealed increasing and decreasing trends in temperature and precipitation, respectively [14-18].

Gridded climate data sets have been used in different studies in the world [19-22]. By studying historical drought events, Salehnia *et al.* [23] and Bannayan *et al.* [24] suggested that AgMERRA data sets fill gaps existing in historical meteorological station-observed data in different climatic regions of Iran. Yaghoubi *et al.* [25] also argued and indicated the high correlation between the minimum and maximum daily temperature attained from synoptic stations and AgMERRA datasets. Lashgari *et al.* [26] investigated the performance of the AgMERRA dataset for estimating the missing data in Mashhad plain and pointed to the high potential of the AgMERRA dataset in simulating maximum and minimum daily temperatures.

Parak *et al.* [14] and Tabari and Talaee [28] investigated trends in daily temperature extremes and annual, seasonal, and monthly maximum and minimum temperatures over Iran during 1961–2010 and 1966–2005, respectively. They represented significant rising trends in temperature indices in all time scales. Tan *et al.* [29] and Tong *et al.* [30] analyzed the trends of precipitation and temperature extremes in Malaysia from 1985 to 2015 and Inner Mongolia from 1960 to 2017, respectively. They indicated that TNmean increased at a higher rate than TXmean, and extreme warm indices significantly increased, whereas extreme cold indices significantly decreased. Worku *et al.* [31] examined the changes in climate extremes in Ethiopia from 1981 to 2014 and suggested some signs for climate change like increasing rainfall extreme events and a warming trend in extreme temperature indices. Zhang *et al.* [32] investigated spatial-temporal variation trends and abrupt changes of the climate extreme indices in Central Asia during 1957–2005 and revealed that the annual mean temperature (Tav), minimum and maximum temperatures significantly increased at a rate of 0.32°C, 0.41°C and 0.24°C per decade, respectively.

Gridded climate data is an alternative idiom for different areas, especially where the density of stations is low or high-quality climate data with appropriate statistical periods are unavailable. Using data stations is of less value and accuracy because only station points can be investigated in terms of trends, not the whole basin, but in the present study, both data stations and AgMERRA datasets have been used to solve this problem. In addition, climate data is regarded as a foundation for a wide range of programs and applied studies in agricultural sciences. Also, changes in meteorological variables in developing countries such as Iran have not received enough concern globally and locally. No comprehensive studies have been carried out on climate change in these regions so that scarce literature reviews can be observed using both station data and AgMERRA data set. Moreover, until recently, there had not been any works on climatic parameters variability and trends using gridded analysis in the Bakhtegan-Maharloo basin. A better understanding of climate change and variability in the Bakhtegan-Maharloo basin, where arid and semi-arid regions occupy most of the land, may greatly improve the managers' and planners' decisions to face more rationally with this situation shortly.

Many studies have been performed on temperature and precipitation in the Bakhtegan-Maharloo basin [33-36], but studies that analyze extreme climate events are rare. Therefore, it is needed to conduct a comprehensive study on the characteristics and evolution of extreme climate events in the Bakhtegan-Maharloo basin by analyzing extreme temperature indices, which are of great significance in predicting catastrophic climate events and preventing and reducing disasters risks in the Bakhtegan-Maharloo basin. Although the AgMERRA dataset has been widely used in various researches worldwide, it has not been used on a local scale specifically for the study area, and surely, information attained from the world scale may not have sufficient capability of being used on a local scale and also it has to be mentioned that AgMERRA dataset has been mostly used for agriculture, not climate change, in studies carried out in Iran.

Alteration occurrence in extremes variability and frequency may result in more severe detriment than the average climatic characteristics. In this regard, humans and the environment are less resilient to the maximums and minimums changes than average conditions changes. So, the analysis of extremes variability is of more significance than the analysis of average climatic conditions. This study aimed to investigate the Spatio-temporal variability of extreme temperature indices in two sections, including gridded analysis and stations analysis over the Bakhtegan-Maharloo basin in Iran from 1980 to 2010. This study provides a better knowledge of the temperature extremes changes in an arid and semi-arid basin. Furthermore, the conclusions will work as a baseline for the projections of future temperature extremes.

Material and Methods

Study Area

The study area is the Bakhtegan-Maharloo basin, located in the northeast part of Fars province in the southwest of Iran (Figure 1). The total area of this basin is 31511km^2, which includes 14881km^2 related to lakes and 16630km^2 related to plains and mountains. Kor River is the most important river in the Bakhtegan-Maharloo basin. The main lakes of the basin are Bakhtegan and Tashk. With a precipitation of 270mm, this basin is one of Iran's most principal agricultural centers [37].

To carry out this research, high-resolution AgMERRA daily maximum and minimum temperature data (0.25°×0.25° horizontal resolution; ~25km) was downloaded from (http://data.giss.nasa.gov/impacts/agmipcf) from 1980 to 2010. These datasets combine daily resolution data from retrospective analyses (the Modern-Era Retrospective Analysis for Research and Applications, MERRA, and the Climate Forecast System Reanalysis, CFSR) with in situ and remotely-sensed observational datasets for temperature, precipitation, and solar radiation, leading to substantial reductions in bias in comparison to a network of 2324 agricultural-region stations from the Hadley Integrated Surface Dataset (HadISD) [10]. Determining the networks of AgMERRA data set that cover the Bakhtegan-Maharloo basin, the grid data was extracted using the R package. For the stations' analysis, after checking the available meteorological stations in the Bakhtegan-Maharloo basin in terms of the length of the data series and also appropriate spatial distribution in the basin, daily maximum and minimum temperature data were obtained from 3 selected meteorological stations across the basin for the study period (Figure 1).

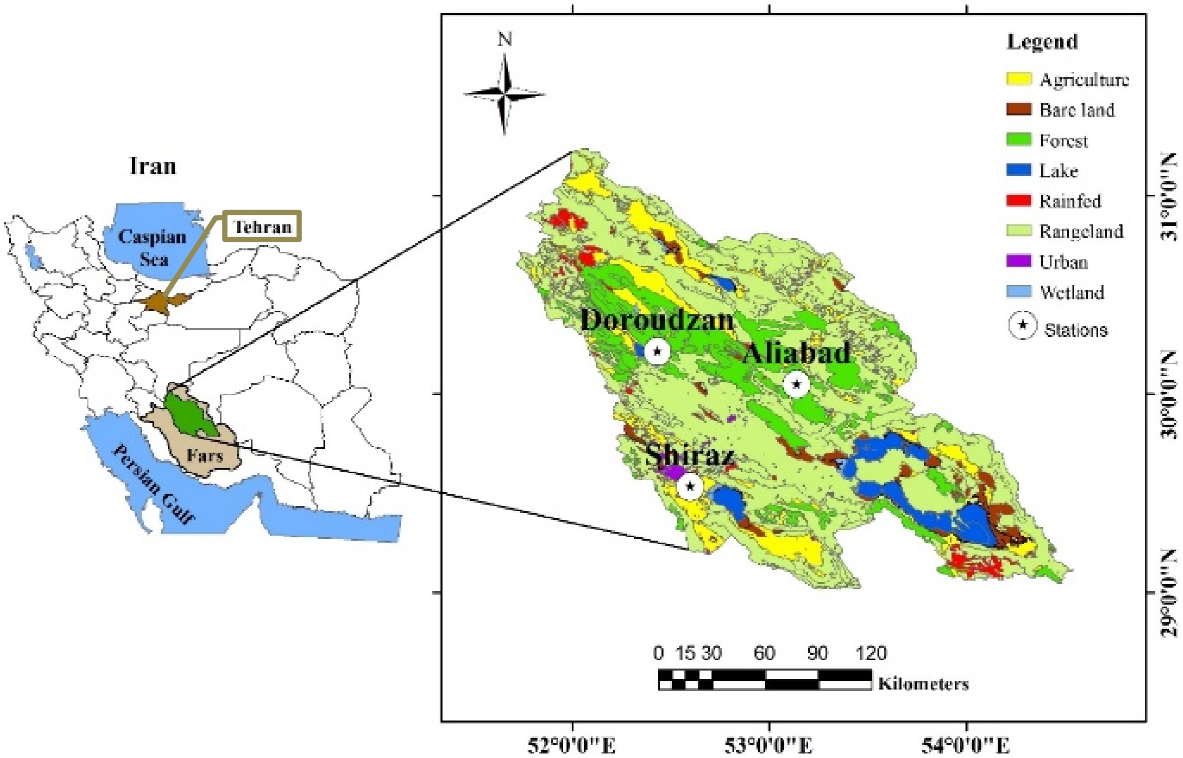

Figure 1) Location of Bakhtegan-Maharloo basin and the meteorological stations in Fars Province in Iran

Data compilation

Selected indices and methodology

Climate change indices were derived from daily temperature data. These indices can be updated and provide a comprehensive view of the temperature changes process [38]. The analysis of these indices varies in different countries and regions according to their conditions [38]. In 1998, CLIVAR (climate variability and predictability), a component of the World Climate Research Programme, conducted extensive studies in different parts of the world and provided various temperature indices such as data frequency based on the minimum and maximum temperature percentiles. Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) recommended 27 core indices, sixteen temperature related and eleven precipitation related indices, derived from daily maximum and minimum temperature and daily precipitation. A full detailed list of the indices can be attained from http://etccdi.pacificclimate.org/list_27_indices.shtml. In this paper, four extreme temperature indices (Table 1) were chosen from the indices recommended by the ETCCDMI. Besides, many aspects of temperature changes are covered by these indices [38]. They are of great importance wholly and specifically for the study area, and a considerable and acceptable calculated p-value has been obtained for these indices considered before choosing them. The cold nights (TN10p) and cold spell duration indicator (CSDI) reflect extreme low-temperature events (cold extremes), and the warm nights (TN90p) and maximum monthly value of daily minimum temperature (TNx) indicate extreme high-temperature events (warm extremes).

Table 1) List of four ETCCDMI Core Indices for the analysis of extreme temperature

Index	Definition	Unit
TNx	Max Tmin: Monthly maximum value of daily minimum temp	°C
TN10p	Cold Nights: Percentage of days when TN<10th percentile	Day
TN90p	Warm Nights: Percentage of days when TN>90th percentile	Day
CSDI	Cold Spell Duration Index: Annual count of days with at least six consecutive days percentile when TN<10th	Day

The indices were calculated by applying the RClimDex software package (Zhang and Yang [39] developed the RClimDex software package at the Climate Research Branch of the Environment Canada on behalf of the ETCCDI). This software computes 27 extreme climate indices (Table 2) and has a graphical capability to display the results.

Table 2) List of ETCCDMI core climate indices [40]

ID	Indicator name	Units
FD0	Frost days	Days
SU25	Summer days	Days
ID0	Ice days	Days
TR20	Tropical nights	Days
GSL	Growing season Length	Days
TXx	Max Tmax	ºC
TNx	Max Tmin	ºC
TXn	Min Tmax	ºC
TNn	Min Tmin	ºC
TN10p	Cool nights	Days
TX10p	Cool days	Days
TN90p	Warm nights	Days
TX90p	Warm days	Days
WSDI	Warm spell duration indicator	Days
CSDI	Cold spell duration indicator	Days
DTR	Diurnal temperature range	ºC
RX1day	Max 1-day precipitation amount	mm
RX5day	Max 5-day precipitation amount	mm
SDII	Simple daily intensity index	mm/day
R10	Number of heavy precipitation days	Days
R20	Number of very heavy precipitation days	Days
Rnn	Number of days above nn mm	Days
CDD	Consecutive dry days	Days
CWD	Consecutive wet days	Days
R95p	Very wet days	mm
R99p	Extremely wet days	mm
PRCPTOT	Annual total wet day precipitation	mm

The methodology adopted in the computation of extreme indices for temperature has been shown in Figure 2 with the help of a flow chart. The daily time series of maximum and minimum temperature are input in RClimdex, and a quality control (QC) function is run to check inhomogeneities present in the data [40]. The main purpose of this data quality control (QC) is to identify errors usually caused by data processing, such as manual keying. If the daily maximum temperature is less than the daily minimum temperature, the procedure automatically sets the missing values for daily maximum and minimum temperatures. In these instances, daily maximum temperatures were manually removed. The quality control procedure also identifies outliers in daily maximum and minimum temperature. These are daily values outside a threshold defined by the user. In this study, this threshold is defined as the mean of the value for the day plus or minus three times the standard deviation of the value for the day (std), that is, [mean – 3 × std, mean + 3 × std] [39]. Daily temperature values outside of these thresholds are marked as potentially problematic; they are manually checked and corrected. Then, extreme indices of temperature are derived using the calculation of the extreme indices function. Trend analysis is also computed by linear least square for four selected extreme temperature indices, and the slopes of the linear trends are computed by the least-squares fitting technique [39]; in this way, the significance of the trends can also be obtained according to the p-value of indices given by the RClimDex software package.

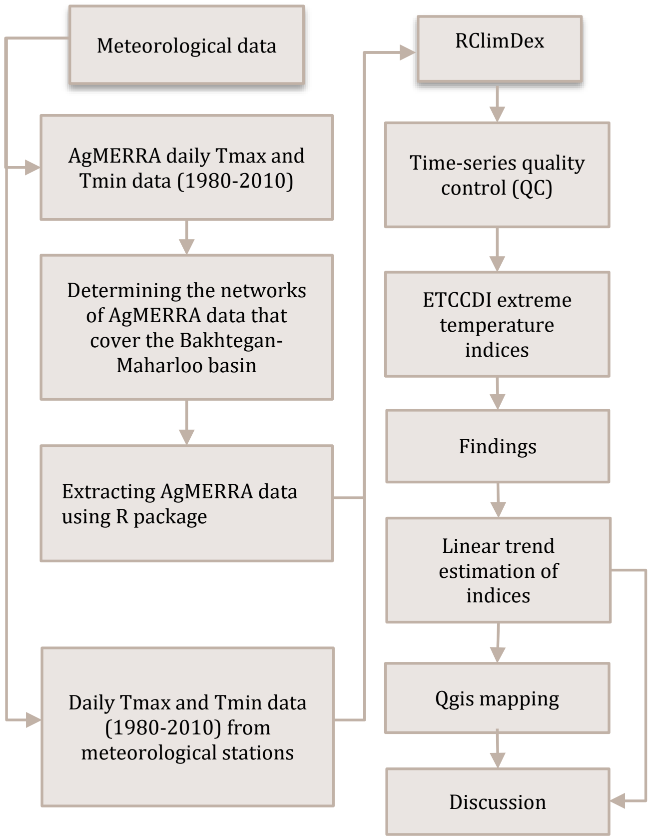

Figure 2) Flowchart of the methodology adopted in the computation of extreme indices

Findings and Discussion

Estimating the extreme temperature indices for the Bakhtegan-Maharloo basin in two sections, gridded analysis, and stations analysis are as follows. The trends of extreme temperature indices obtained from AgMERRA data analysis are given in Figure 3. The trend of extreme temperature indices obtained from Shiraz, Aliabad, and Doroudzan stations data analysis are given in figures 4, 5, and 6, respectively.

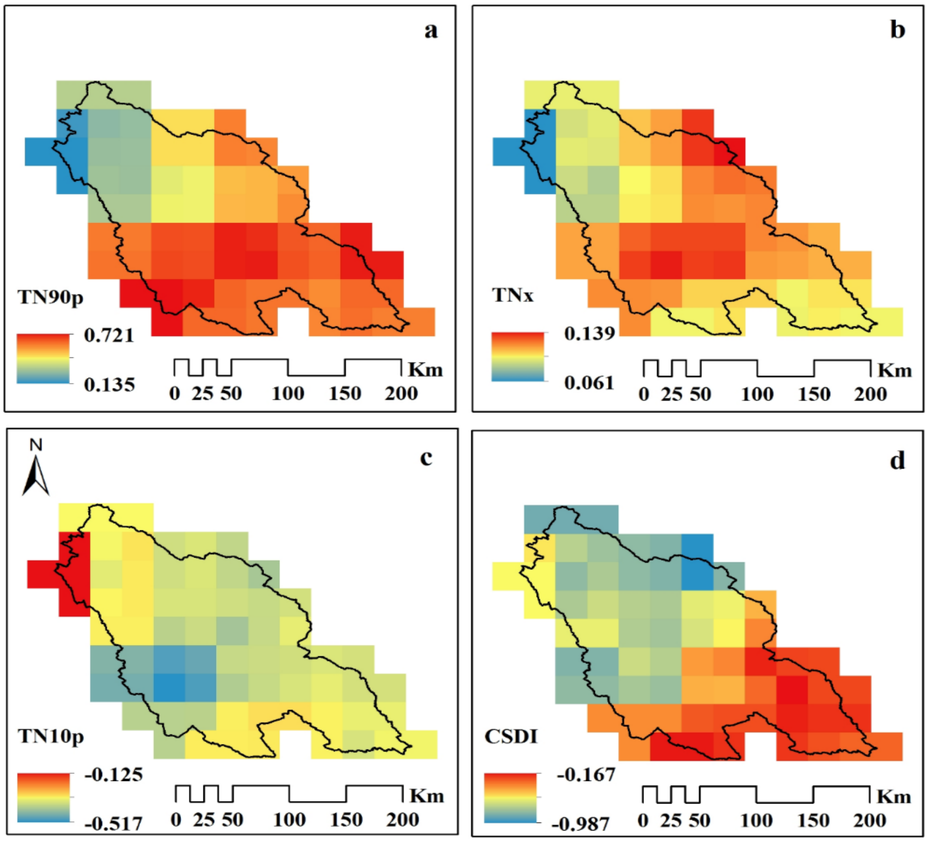

Figure 3) The trends in TN90p (a), TNx (b), TN10p (c), and CSDI (d) obtained from the analysis of AgMERRA data for the 1980–2010 period over the Bakhtegan-Maharloo basin.

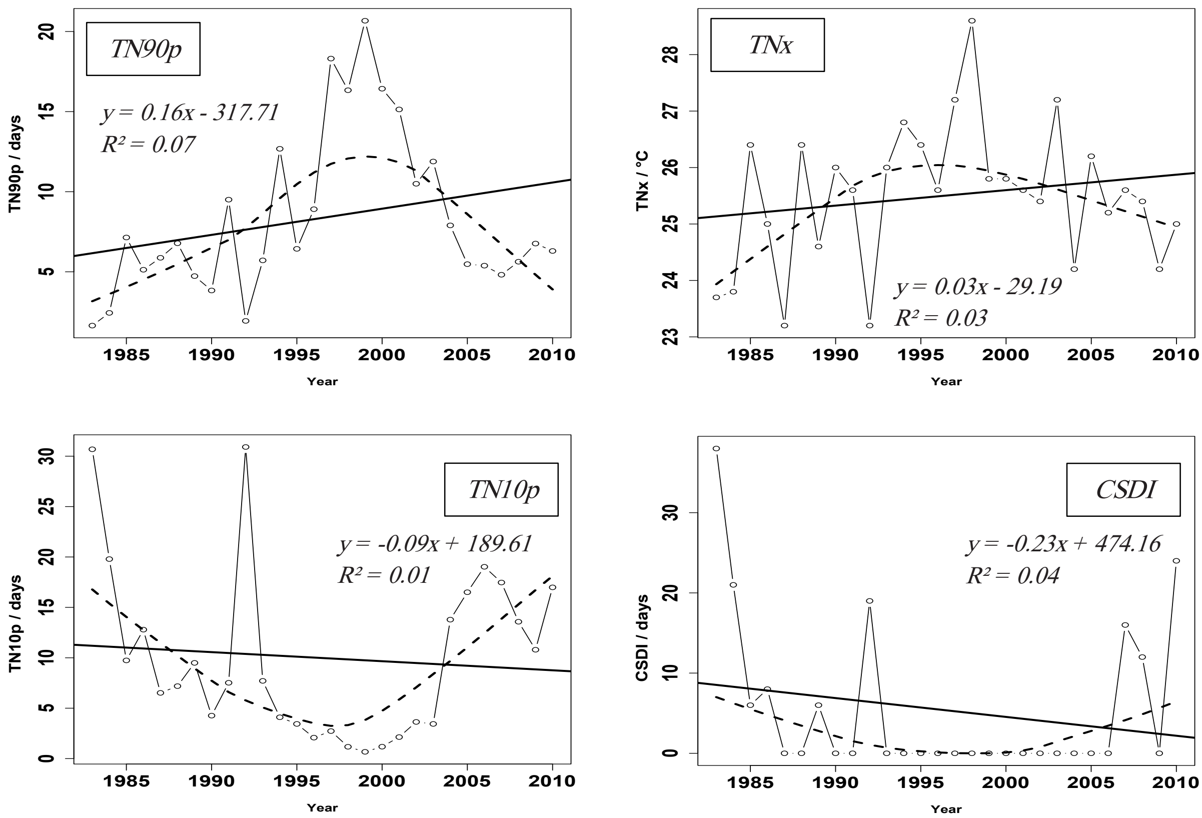

Figure 4) The trends in TN90p, TNx, TN10p, and CSDI in Shiraz station for the 1980–2010 period

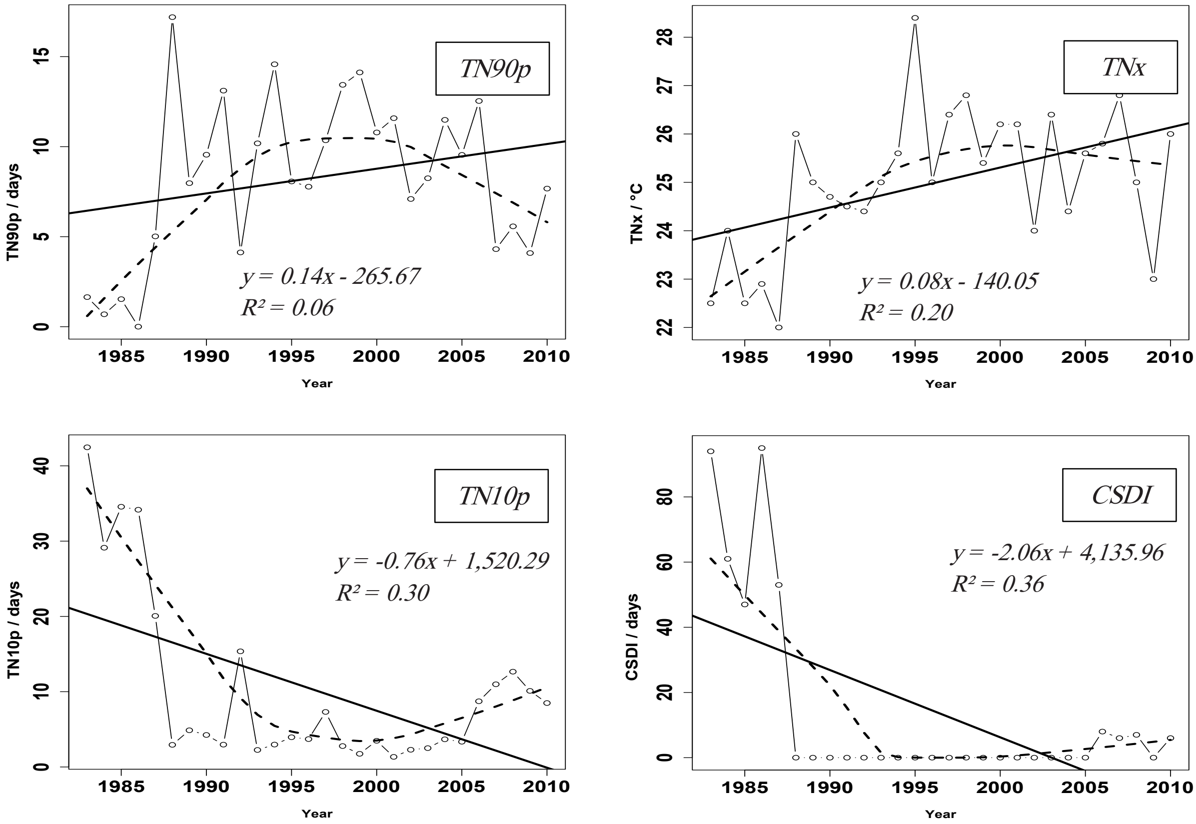

Figure 5) The trends in TN90p, TNx, TN10p, and CSDI in Doroudzan station for the 1980–2010 period

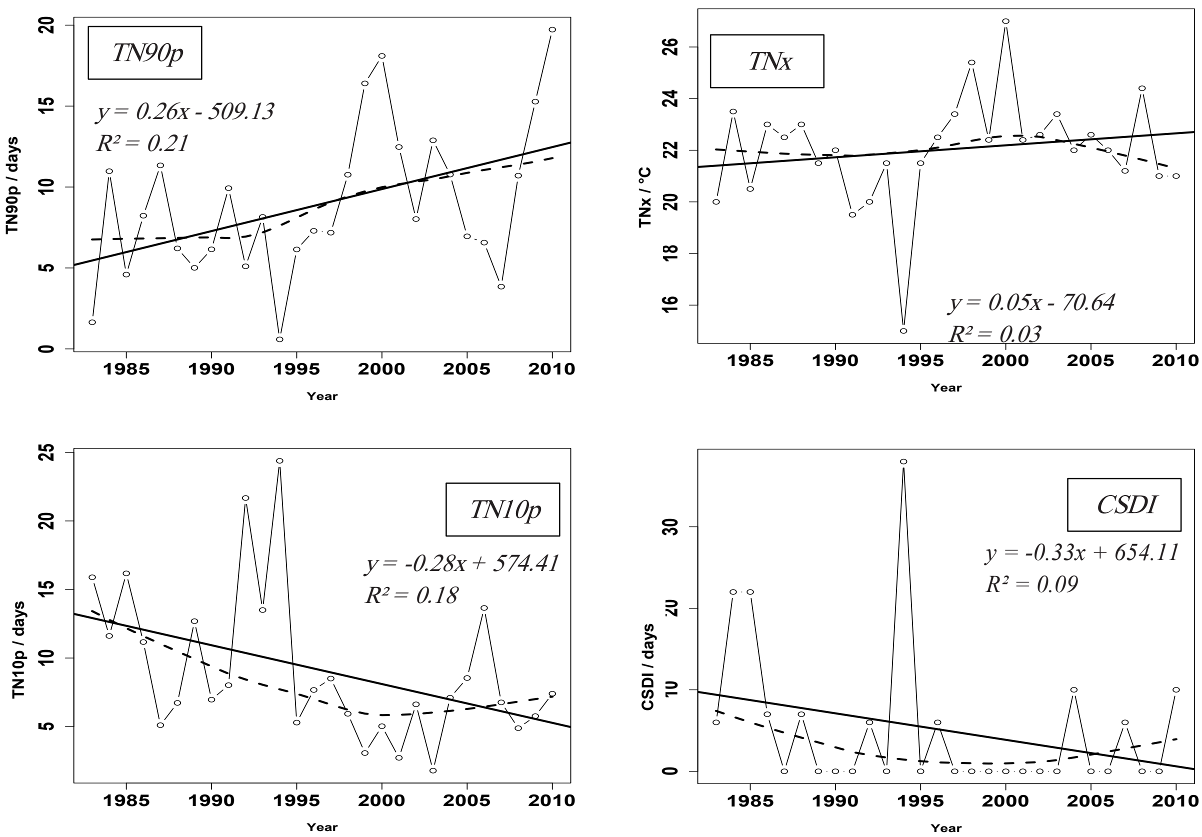

Figure 6) The trends in TN90p, TNx, TN10p, and CSDI in Aliabad station for the 1980–2010 period

Warm nights (TN90p)

According to the AgMERRA data results and station data of warm nights (TN90p), an increasing trend can be observed in the whole basin (Figure 3-a, 4, 5, and 6). The trend of this index changes from 0.135 to 0.721 in different parts of the basin. This index shows a more increasing trend in the south of the basin than in the north.

Maharloo, Tashk, and Bakhtegan Lakes and saline lands around them are located in the south part of the basin. This region has a semi-arid climate. Its reason may be related to the lakes area growth during these years, which may greatly impact the albedo and, as a result, on night temperature in these areas. In a study carried out in New South Wales in 1985 April, the rate of albedo on salt lake surface was 60%. However, it was 32% on adjacent sand dunes with a high-temperature difference, in a way that the mean temperature during night was 0.4˚C on sand dunes and 8˚C on a salt lake. It was concluded that the Surface Energy Balance Model was of great importance, and the effects of albedo have caused temperature differences between different surfaces during the night [41]. It can also be mentioned that an increase in the number of greenhouse gases affects the number of waves reflecting from the earth and increases the amount of moisture during the night, causing warm nights (TN90p). This factor is more pronounced in late summer. When the atmosphere has the maximum storage capacity of moisture, this increasing trend on TN90p corresponds to the studies of Rahimzadeh *et al.*, Worku *et al.,* and Niu *et al.* [12, 15, 31] follows global warming.

Monthly Maximum value of daily minimum temperature (TNx)

The maximum monthly value of daily minimum temperature (TNx) increases the slope in the whole basin (Figure 3-b). The trend of this index changes from 0.061 to 0.139 in different parts of the basin. The trend of this index alteration in the northwestern part is less than in other parts of the basin. The results of the maximum monthly value of daily minimum temperature (TNx) based on station data indicate an increasing trend in all three stations (Figure 4, 5, and 6). The increasing trend of the maximum monthly value of daily minimum temperature (TNx) is consistent with various studies in different parts of the world [29, 32, 42]. The maximum rates of TNx are mostly observed in the central part of the basin and can be referred to as the agricultural land use developed in recent years. Among the factors that influence the rate of daily minimum temperature, population increase, vehicles and industrial plants development, and, as a result, increasing greenhouse gas emissions in the urban areas are of great importance. As it is obvious in the land use map (Figure 1) and Figure 3, Shiraz city is also located in the pixels showing the maximum rates of TNx. It has to be mentioned that this part of the basin has an arid and semi-arid climate which exacerbates the conditions and accelerates global warming speed.

Cold extremes include the occurrence of cold nights (TN10p)

According to the results of AgMERRA data, the occurrence of cold nights (TN10p) has a decreasing trend in the whole basin (Figure 3-c). The trend of this index changes from -0.517 to -0.125 in different parts of the basin. The results of cold night occurrence (TN10p) based on station data indicate a decreasing trend in all three stations (Figure 4, 5, and 6). Among the factors reducing the occurrence of cold nights like the role of population growth, increase in vehicles and industrial factories, and consequently an increase in greenhouse gases in the urban atmosphere, other factors need to be addressed on a larger scale, including global warming. Considering land use in the study area, a portion of the western part showing a more decreasing trend is saltland which may result from irrigated agriculture and urbanization under semi-arid climate conditions. So the mentioned values can be related to the rate of albedo, which has increased the night temperature caused by salt crusts, which is the consequence of irrigated agriculture. The universal development of irrigated agriculture in arid lands caused scientists to suppose salinization as an important factor caused by irrigation, impacting albedo and the local climate, specifically in arid and semi-arid regions [41].

On the other hand, the west northern part with the lower decreasing trend is mostly allocated for rangelands and rainfed under Mediterranean climate conditions. This difference in climates that can exacerbate the conditions and the type of land use would be of great importance in decreasing trend differences. Of course, the whole basin has a decreasing trend. The declining trend in the occurrence of cold nights' index can be justified by studies conducted around the world [3, 15, 30, 38].

Cold Spell Duration Indicator (CSDI)

According to the results of AgMERRA data, Cold Spell Duration Indicator (CSDI) has a decreasing trend in the whole basin (Figure 3-d). The trend of this index changes from -0.987 to -0.167 in different parts of the basin. As we move from the northwest to the southeast of the basin, the decreasing trend of changes becomes less. In the northwestern part of the basin, agricultural lands are seen. These lands continue southeastward from Abadeh to Kafter Lake that is in the east of Eghlid. This area has a Mediterranean climate. Tashk Lake and Bakhtegan Lake and saline lands are located in the southeastern part of the basin with a semi-arid climate. The Cold Spell Duration Indicator (CSDI) analysis based on stations data indicates a decreasing trend in all three stations (Figure 4, 5, and 6). The decreasing trend of the cold spell duration indicator (CSDI) corresponds to the studies in the world [14, 15, 30, 31], and it can also be related to land use. As seen in the literature review, day and night temperature is mostly affected by albedo on the local scale, depending on the land surface. Here, the southern part has experienced a cooler daytime and hotter nights under drier conditions than the northern parts with no salt trace and rangeland and rainfed agriculture land use under wetter climate conditions. Probably, the accompanying of climate conditions with land use has resulted in the mentioned results.

Conclusion

Changes in the variability and frequency of extremes can have more severe damage than changes in the average climatic characteristics. Also, humans and the environment show reaction to the changes of the maximums and minimums more than the changes in the average conditions. Therefore, analysis of variability in extremes is more important than the variability in average climatic conditions. This study aimed to analyze the trends in temperature extremes of the Bakhtegan-Maharloo basin in the southwest of Iran using the ETCCDI indices. This study showed that temperature extremes in the Bakhtegan-Maharloo basin were increasing during the study period. Temperature analysis corresponded to the region's warming and showed that warm extremes, including warm nights (TN90p) and maximum daily minimum temperature (TNx), have an increasing trend in the study area, and the trends were significant at the 95% confidence level. The trends of cold extremes were decreasing in the basin. The percentage of days with maximum and minimum temperature less than the tenth percentile has changed, and these signs show a decrease in the occurrence of cold nights (TN10p). In general, the results showed that the frequency and intensity of cold extremes have decreased; however, warm extremes significantly increased.

Maybe adding data from 2010 to 2019 to the meteorological time series would result in different conclusions and be suggested for future studies. It is of great interest and also needs to study the effects of land use on local climates. Considering the effect of temperature extremes on human activities such as energy, agriculture, environment, water resources management, and building design, it is also necessary to consider the effects of these extreme climatic events in future planning and policy-making in different sections.

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