Future Climate Projection and Zoning of Extreme Temperature Indices

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Abstract

Global warming due to increasing carbon dioxide emissions over the past two centuries has had numerous climatic consequences. The change in the behavior and characteristics of extreme weather events such as temperature and precipitation is one of the consequences that have been of interest to researchers worldwide. In this study, the trend of 3 extreme indices of temperature: SU35, TR20, and DTR over two future periods have been studied using downscaled output of 3 GCMs in Razavi Khorasan province, Iran. The results show that the range of temperature diurnal variation (DTR) at three stations of Mashhad, Torbat-e-Heydarieh and Sabzevar during the base period has been reduced significantly. The trend of the number of summer days with temperatures above 35°C (SU35) in both Mashhad and Sabzevar stations was positive and no significant trend was found at Torbat-e-Heydarieh station. The number of tropical nights index (TR20) also showed a positive and significant increase in the three stations under study. The results showed highly significant changes in temperature extremes. The percentage of changes in SU35 index related to base period (1961–2014) for all three models (CNCM3, HadCM3 and NCCCSM) under A1B and A2 scenarios indicated a significant increase for the future periods of 2011–2030 and 2046–2065. TR20 is also expected to increase significantly during the two future periods. The percentage of changes of DTR into the future is negligible.

1. Introduction

The global warming due to increasing greenhouse gases in atmosphere during recent decades has had significant effects on atmospheric phenomena and biological activities of living organisms on the planet's surface, and this has been the subject of interest by various scientists. The change in the behavior and characteristics of climate variable has shown the effects of global warming on these variables (Stocker et al. 2013). There is observational evidence of long-term changes in weather and climate extremes across the globe with significance dependent on variables, seasons and regions (IPCC 2013).

An extreme event is a rare phenomenon that is statistically located in the upper and lower regions of the statistical distribution, and hence the probability of its occurrence is very low. The extreme weather and climate events include cold and hot waves, floods and droughts occurring under conditions of global warming caused by increase of greenhouse gases, changes in mean climate parameters, and the frequency of extreme meteorological events (Rosenzweig et al. 2001).

The World Meteorological Organization's Climate Commission has introduced 27 precipitation and temperature extreme indices (including 16 temperature extreme indices and 11 precipitation extreme indices) (Peterson 2005; Zhang et al. 2011). Extensive research has been done globally to investigate the effects of global warming on climate extreme indices. The climate models (GCMSs) predict that the hydrological cycle is likely to be intensified and results in occurrence of floods and droughts. On the one hand, winter precipitation is mostly rain and snow zones and spring runoff are reduced and spring and summer droughts are intensified. Also, higher latitudes and heights will have higher temperatures than the global mean temperature, especially in winter and night (the minimum temperature) are expected to increase unevenly (Rosenzweig et al. 2001).

Frich et al. (2002) using 10 temperature and precipitation indices investigated changes in these indices in the second half of the 20th century. The results showed changes in temperature indices, especially increase in summer night heat, reduction in the number of frost days and reduction in maximum annual temperature. In another study, (Yue and Hashino 2003) studied the monthly, seasonal, and annual temperature trends in Japan for the past hundred years. According to the study results, the annual temperature of the 46 stations evaluated by MK test between 1900 and 1996 increased from 0.51 to 2.77 degrees Celsius. Studies conducted in the United States (DeGaetano 1996), Australia, New Zealand (Plummer et al. 1999), China (Zhai et al. 1999), Canada (Bonsal et al. 2001) also showed a reduction in the number of frost days in the upper and middle latitudes of the northern hemisphere and an increase in the length of the growth period compared to the 20th century.

Studies on the effects of climate change on growth period duration include those on the temporal and spatial variability of phonological seasons in Germany from 1951 to 1996 (Menzel 2003), the beginning of spring in China (Schwartz and Chen 2002), changes in the growing season in the last century (Linderholm 2006). In Iran, several studies have been conducted on the effects of global warming on climate parameters, which can be mentioned in the following. Some studies have also examined the accuracy of climate models for projecting the future of climatic elements and extreme indices, including (Khan et al. 2006), (Chen et al. 2013) and (Roshan et al. 2013). Many studies have been conducted on the trend and prediction of climatic elements and extreme indices in Iran. The study results of Nasiri Mahali et al. (2006) show that due to delay in date of occurrence of first autumn frost and early last spring frost date in Iran, growth season duration in all studied stations increased 5–23 days and 16–42 days for 2025 and 2050, respectively. In a similar study, Esmaili et al. (2011) evaluated the changes on growth period duration and spring and autumn frost data caused by climate changes in Razavi Khorasan province in Iran. Others conducted on the trend and projection of climatic variables and extreme indices in Iran ((Jahanbakhsh Asl and Torabi 2004), trend of extreme temperature and precipitation indices in Tehran (Mohammadi and Tagavi 2007), trend Analysis of extreme precipitation Indices in Iran (Asgari et al., 2007), trend of Climate extreme Indices over Iran during 1951–2003 (Rahimizadeh et al., 2009), study of the climate change impacts on agricultural products and agro-climatic variables in Razavi Khorasan (Babaeian and Kouhi 2012), the study of impact of climate change on the probabilistic characterizations of drought events in western stations of Iran (Fattahi et al. 2015), assessing the impact of climate change on water resource using the output of Canadian Global Coupled Model (CGCM 3.1) under A1B, B1 and A2 scenarios (Abbaspour et al. 2009), study the future of extreme precipitation and temperature in Iran (Vaghefi et al. 2019), Comparison of LARS-WG and RegCM4 models' performance for simulation and post processing of Khorasan temperature and precipitation data (Ahmadi et al. 2016).

In the present study, in addition to investigating the trend of temperature extreme events (SU35, TR20, and DTR) in Razavi Khorasan province, Iran, the future prospects of these extreme events are also provided using downscaled outputs of three general atmospheric circulation models (HadCM3, CNCM3, and

NCCCSM) under A1B and A2 scenarios using LARS-WG model for the two forthcoming periods 2011–2030 and 2046–2065.

2. Materials And Methods

2.1 Study area

In recent years, Iran has been experiencing increasing number of extreme events such as heat waves, drought and flooding (CRED, 2018). The present study has been conducted in Razavi Khorasan province, northeast of Iran. The geographical location of the province and the meteorological stations under study are presented in Fig. 1. The daily temperature data of 8 synoptic stations of Razavi Khorasan Province (Mashhad, Quchan, Golmakan, Gonabad, Sabzevar, Kashmar, Sarakhs and Torbat-e-Heydariyeh synoptic stations) were used for conducting this study.

2.2 Extreme indices

An extreme event is a rare phenomenon that is statistically located in the upper and lower regions of the statistical distribution and hence the probability of that event occurrence is very low. The joint World Meteorological Organization (WMO) Commission for Climatology (CCl)/World Climate Research Programme (WCRP) project on Climate Variability and Predictability (CLIVAR)/Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Climate Change Detection and Indices (ETCCDI) has recommended a vast range of climate extreme indices (Peterson 2005; Yuan et al. 2005). In this study, 3 of the 16 temperature extreme indices including SU35, TR20, and DTR were used (Table 1). The extreme temperatures were categorized into cold and warm events: the former includes cold days, frost days and cold surges during winter (December-January-February) and the latter includes tropical nights, warm days, and heat waves during summer (June-July-August. In this study, Rclimdex software package has been used under R programming language recommended by WMO to calculate temperature extreme indices.

Table 1
The used extreme Temperature indices recommended by CCL/CLIVAR Expert Group (Sillman and Roechner, 2007)

ID	Definitions	Unit
SU	Let Tx_{ij} be the daily maximum temperature on day i in period j. count the number of days where Tx_{ij}>35 ˚C	days
TR	Let Tn_{ij} be the daily minimum temperature on day i in days period j. Count the number of days where Tn_{ij} >20 ˚C	days
DTR	Let Tn_{ij} and Tx_{ij} be the daily minimum and maximum temperature respectively on day i in period j. If I represents the number of days in j, then $DTR_j= \sum(Tx_{ij}-Tn_{ij})/I$	days

2.3 Detecting the Trend of extreme indices

Man-Kendall method was used as one of the non-parametric tests to detect the trend in extreme temperature indices (Khosravi et al. 2017). Among the synoptic stations of Razavi Khorasan Province, only the three of them (Mashhad, Sabzevar and Torbat-e-Heydariyeh) have long-term recorded data for more than 30 years. Therefore, the trend of the extreme temperature indices of these 3 meteorological stations was investigated.

2.4 General Circulation Models

There are different methods to simulate climate variables in the future periods that weather circulation model is the most valid. Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. Table 2 presents the profile of the used climate models in this study.

Table 2
Characteristics of the GCMs used in this study (Macmahon et al.2015)

Climatic Global Models	Emission Scenarios	Resolution	Country
HadCM3	SRA1B, SRA2, SRB1	3.75°*2.5	UK
NCCCSM3	SRA1B, SRA2, SRB1	1.4*1.4 °	USA
CNRM3	SRA1B, SRA2	2.8*2.8 °	France

2.5 LARS-WG

Low spatial and temporal resolution of GCMs and uncertainty in their daily outputs especially precipitation have made inappropriate the direct use of these outputs in analysis of extreme events and their application in different applied models. Therefore, to use these data, the models outputs should be downscaled at the station level through various techniques. Downscaling methods include dynamic downscaling using regional climate models such as RegCM, statistical downscaling such as SDSM and ASD model, and stochastic weather generator models such as LARSWG (Semenov 2008). The Long Ashton Research Station–Weather Generator (LARS-WG) model is widely used to downscale the GCM outputs in climate change studies (Semenove 2002). Semi-Empirical Distribution (SED) model is used in this approach to estimate the probability distribution of wet and dry series, daily precipitation, minimum and maximum temperature, and solar radiation. The main objective of LARS-WG was to overcome the limitations of the Markov chain method in precipitation. The performance of this model was evaluated by Semenov at 18 stations in Asia, the US and Europe in 1998 (Semenov and Brooks 1999).

2.6 Percentage of changes in extreme indices in the future period (2011–2030) and (2046–2065)

The simulated indices using the outputs of three GCMs (HadCM3, CNCM3, and NCCCSM3) for two future periods (2011–2046 and 2046–2065) under A1B and A2 scenarios were compared to the base period (1961–2014) on the station scale and in order to reduce uncertainty (IPCC 2013), the mean of the indices calculated for the three models was obtained (for all models the same was performed without weighting). Finally, the percentage change of the index was calculated by the following equation (Wilby et al. 2002).

$$\Delta 2020s = \frac{(V2020s - Vbase) * 100}{Vbase} \quad (1)$$

Where $\Delta 2020_S$ is the percentage of the change in the index over period (e.g. 2020) relative to base period, $v2020s$ is the value of the index (or any of the indices) in the period (2020 here) and v_{base} is the value of the index during the base period (1961–2014).

All stages of the research method for predicting and detecting the spatio-temporal changes in temperature and temperature indices in Razavi Khorasan province using LARS-WG are shown in Fig. 2.

3. Results And Discussion

3.1 Calibration and validation of LARS-WG

Daily climate data were used for calibration and validation of LARS-WG. The data were imported into the weather generating module and the statistical properties of SED were computed and monthly climate variables were calculated for each month along with variances. Numbers of runs were given with different random seed value to generate the synthetic data having the same statistical properties as of the observed data (Kumar et al. 2014). In order to evaluate LARS-WG model for simulating weather data, variances and mean values of climate variables were compared using F and T tests (Semenov 2008). For model evaluation, the simulated temperature and related extreme indices were compared with extreme temperature indices based on observation data. This comparison showed that the LARS-WG is able to realistically simulate the temperature and extreme indices (Table 3)

3.2 Extreme temperature indices for selected stations

Extreme temperature indices at the selected stations were calculated using Rclimdex package in R software and the results for base period are presented in Table 3.

3.2.1 Number of Summer Days (SU35)

The mean number of summer days (SU35) which are days with the maximum temperatures above 35 degrees Celsius in Razavi Khorasan province is 46 days a year, with a maximum of 94 days at Sarakhs station in the northeast of the province and a minimum of 8 days at Quchan station in the north of the province. The coefficient of variation is 71.5% which indicates the variation of this index at the provincial level.

3.2.2 Number of Tropical Nights (TR20)

In the south of the province, the number of tropical nights is more than 70 nights a year. This index range from 85 days in Kashmar station to 2 days at Quchan station. The coefficient of variation is 76%.

3.2.3 Diurnal temperature range (DTR)

Monthly mean difference between TX and TN in the study area is shown in Table 3. The highest index belongs to Mashhad station with 13.9°C and the lowest index belongs to Kashmir station with 11.8°C. The coefficient of variation is 5%.

Table 3
Extreme temperature indices for base period based on observation and WG simulations

Stations	SU35	SU35-WG	TR20	TR20-WG	DTR	DTR-WG
Mashhad	27.4	25.5	21	19.2	13.9	13.8
Quchan	8	4.4	2.04	5.6	13.5	13.5
Golmakan	14.5	10.9	7.88	5.6	13.7	13.7
Gonabad	62.7	58.9	69.1	65.5	12.9	13
Kashmar	65.5	62.7	85.4	83	11.7	11.8
Sabzevar	76.5	80.8	75.8	77.5	13.4	13.6
Sarakhs	94	91.1	72.3	70.2	13.8	13.6
Torbat-e-Heydarieh	17.9	16.6	24.8	23.2	13.8	13.3
Mean	46	43.8	44.8	43.7	13.3	13.4
Minimum	8	4.4	2	5.6	11.8	11.8
Maximum	94	91.1	85.4	83	13.9	13.8
C.V	71.5	76.5	76	76.2	5.3	5.1

3.3 Trend Analysis during 1961–2014

The trend of extreme temperature indices was calculated using Mann-Kendall, a non-parametric test, for the three stations of Mashhad, Sabzevar and Torbat-e-Heydariyeh during the period 1961–2014.

Based on Mann-Kendall test results, the trend of DTR at the three stations of Mashhad, Torbat-e-Heydarieh, and Sabzevar showed a significant decreasing trend at the 0.01 level. The number of summer days with temperatures above 35°C (SU35) at Mashhad and Sabzevar stations indicated a positive trend. This index at Torbat-e-Heydariyeh Station showed no significant trend. The index of the number of tropical nights (TR20) in three stations Mashhad, Torbat-e-Heydariyeh indicated a positive and significant trend.

3.4 Projected extreme temperature indices for the future periods (2011–2030 and 2045–2065)

In order to provide an overview of the future changes in extreme temperature index relative to the base period of 1961–2014, we used the output of the three GCMs (HadCM3, NCCCSM, and CNCM3) under A1B and A2 emission scenarios downscaled using LARS-WG model for the two periods of 2011–2030 and 2046–2065 for the selected stations in Razavi Khorasan province (Tables 4, 5 and 6).

3.4.1 The changes in extreme temperature indices relative to base period under two A2 and A1B emission scenarios

The level of changes in extreme temperature indices under two A2 and A1B emission scenarios during the period of 2011–2030 and 2046–2065 were calculated using the output of three GCMs for Razavi Khorasan stations, however, the results were only indicated for Mashhad station (Table 7).

3.4.1.1 The projected changes in extreme temperature indices for the period of 2011–2030

The percentage of changes in SU35 index related to base period under A1B and A2 scenarios for all three models CNCM3, HadCM3 and NCCCSM will likely projected to increase under the scenario A1B. The increase was estimated 80, 71 and 98%, respectively, and in the case of A2 it will be 54, 53 and 99.7%, respectively. The mean of three models under A1B and A2 scenarios showed an increase of 83% and 69% respectively. The absolute changes in the mean of the index relative to the base period were 21, 18 and 25 days for CNCM3, HadCM3 and NCCCSM models under A1B scenario, respectively, and 14, 14 and 25 days under scenario A2, respectively (Table 7).

The percentages of changes in the TR20 index for the forthcoming period of 2011–2030 for CNCM3, HadCM3, and NCCCSM under A1B scenario will likely increase by 71, 55 and 81%, respectively. Under another scenario, A1B, it will be 43, 44 and 81% respectively. The mean of these models were estimated 69% and 56% under the scenario A1B and A2 respectively. The absolute changes in this index compared to the base period during 2011–2030 were calculated 14, 11 and 16 days under A1B scenario and 8, 8 and 16 days under the scenario A2 for CNCM3, HadCM3 and NCCCSM models respectively. The mean of these changes compared to base period was estimated 13 and 11 days under A_1B and A2 scenarios respectively. The differences between other extreme temperature indices studied in two periods (base period and 2011–2030) were negligible (Table 7).

Table 7
Changes in extreme temperature indices using outputs of GCMS under two emission scenarios of A2 and A1B during 2011–2030 at Mashhad station

Scenario	Models	DTR	SU35	TR20
	Base period (WG)	13.8	25.5	19.2
A1B	CNCM3	13.8	46.0	32.9
	HadCM3	13.8	43.5	29.8
	NCCCSM	13.9	50.4	34.7
A2	CNCM3	13.9	39.3	27.6
	HadCM3	13.8	39.0	27.6
	NCCCSM	13.9	50.9	34.9
Average scenario A1B		13.8	46.6	32.5
Average scenario A2		13.9	43.9	30
Percentage change related to base period				
	CNCM3	0.1	80	71
A1B	HadCM3	-0.2	71	55.0
	NCCCSM	0.4	98	81
	CNCM3	0.5	54	43.4
A2	HadCM3	-0.2	53	43.6
	NCCCSM	0.4	99.7	81.3
Average scenario A1B		0.1	82.9	68.9
Average scenario A2		0.2	69.0	56.1
Absolute difference				
A1B	CNCM3	0.0	21	13.7
	HadCM3	0.0	18.0	10.6
	NCCCSM	0.1	25	15.5
A2	CNCM3	0.1	14	8.3
	HadCM3	0.0	14	8.4
	NCCCSM	0.1	25	15.6
Average scenario A1B		0.0	21	13.3

Scenario	Models	DTR	SU35	TR20
Average scenario A2		0.0	18	10.8

3.4.1.2 The projected changes in extreme temperature indices for the period of 2046–2065

The percentage change in SU35 index under A1B and A2 scenarios for CNCM3, HadCM3 and NCCCSM were estimated 154, 185 and 206%, respectively under A1B scenario and 173, 183 and 220% under the alternative scenario. The mean increase was 182% and 192% under A1B and A2 scenarios respectively. As the results showed, absolute changes in this index in CNCM3, HadCM3 and NCCCSM models were estimated 39, 47 and 53 days under A1B scenario and 44, 47 and 56 days under A2 scenario respectively (Table 8).

This index will increase in CNCM3, HadCM3, and NCCCSM models under A1B scenario by 135, 167 and 190 percent, and under another scenario by 159, 168 and 209 percent respectively. However, the mean of all the above three models will increase by 164 and 179 percent under A1B and A2 scenarios, respectively. The absolute change in the number of summer days related to base period will likely be 26, 32 and 36 days in CNCM3, HadSM3 and NCCCSM models, respectively. In alternative scenario, these differences will be31, 32, and 40in CNCM3, HadSM3 and NCCCSM models, respectively. The mean of obsolete change in this index were estimated 32 and 34 days under A1B and A2 scenarios respectively. The change of DTR index over the period of 2046–2065 related to the base period is not considerable.

Table 8
Extreme temperature indices calculated using outputs of three models under Two Emission Scenarios A2 and A_1B at Mashhad Station during the period of 2046–2065

Scenario	GCMs	DTR	SU35	TR20
A1B	Base period (WG)	13.8	25.5	19.2
	CNCM3	13.9	64.8	45.2
	HadCM3	13.9	72.6	51.3
	NCCCSM	13.9	78.0	55.7
A2	CNCM3	13.8	69.7	49.7
	HadCM3	13.8	72.2	51.6
	NCCCSM	13.9	81.5	59.5
Average (A1B scenario)		13.9	71.8	50.7
Average (A2 scenario)		13.8	74.5	53.6
Percentage change related to base period				
	CNCM3	0.5	154	135
A1B	HadCM3	0.5	185	167
	NCCCSM	0.7	206	190
	CNCM3	0.0	173	159
A2	HadCM3	-0.2	183	168
	NCCCSM	0.5	220	209
Average (A1B scenario)		0.5	182	164
Average (A2 scenario)		0.1	192	179
Absolute Difference				
	CNCM3	0.1	39	26
A1B	HadCM3	0.1	47	32
	NCCCSM	0.1	53	36
	CNCM3	0.0	44	31
A2	HadCM3	0.0	47	32
	NCCCSM	0.1	56	40
Average (A1B scenario)		0.1	46	32

Scenario	GCMs	DTR	SU35	TR20
Average (A2 scenario)		0.0	49	34

3.4.2 Spatial-temporal analysis of SU35 extreme indices in Razavi Khorasan Province

The spatial patterns of the extreme temperature indices (SU35, TR20, and DTR) under A2 and A_1B scenarios during the future periods of 2011–2030 and 2046–2065 for Razavi Khorasan province are plotted. In this section, only the spatial distribution of SU35 is provided for instance (Fig. 3).

According to the mean of three models under scenario A2, this index is increased at all stations studied, with the maximum increase by 16 and 20 days in Mashhad and Sabzevar stations, respectively. The minimum is expected to occur in Quchan and Golmakan stations by 4 to 8 days. Under A1B scenario, this index increased at all stations under study. Mashhad and Sabzevar stations will likely experience the maximum increase by 20 to 24 days. The minimum of this index will occur at Qouchan station (4 to 8 days) during 2011–2030 (Fig. 4).

According to the average of three GCMs under A2 scenario, SU35 extreme index will have a significant increase in all stations studied during the forthcoming period of 2046–2065, with the highest increase at Gonabad and Mashhad stations with 43 to 50 days and the lowest increase at Quchan stations with 15 to 22 days (Fig. 5). According to the scenario A1B, this index will also increase at all stations studied, with the highest increase at Mashhad and Gonabad stations between 40 and 48 days and the lowest increase at Quchan station with 16 to 24 days during 2046–2065 (Fig. 6).

4. Conclusion

The trend of extreme temperature indices was estimated using non-parametric Mann-Kendall test for three stations of Razavi Khorasan including Mashhad, Sabzevar and Torbat-e-Heydariyeh during the based period of 1961–2014. The results show that the range of diurnal temperatures range (DTR) in three stations during the above period indicated a significant decreasing trend at the 0.01 level. The number of summer days with temperature above 35°C (SU35) in two stations (Mashhad and Sabzevar) showed a positive trend and no significant trend at Torbat-e-Heydariyeh station. The index of number of tropical nights (TR20) at three stations under study also showed a significant increasing trend.

The objective of this study was to determine potential future temperature–base extremes indices and to assess spatial and temporal changes in these extreme indices in Razavi Khorasan province under two greenhouse gas emissions scenarios (A2 and A1B) in two time spans as 2020s (2011–2030), 2055s (2046–2065). The daily temperature data of IRIMO were used to downscale outputs from three General Circulation Models (GCMs) using LARS-WG. In this study the ability of the LARS-WG stochastic weather generator to simulate extreme means of daily and monthly temperatures events for a period of 54-yr (1961–2014) was tested at synoptic stations of Razavi Khorasan province. The extreme indices were calculated using outputs of three models. The results indicate that the mean of absolute difference of SU35 for all three CNCM3, HadCM3 and NCCCSM models is expected to increase for the future period of 2011–2030. The mean are likely to be 21 and 18 days in A1B and A2 scenarios respectively. There is also a significant increase in this index for the period of 2046–2065. The mean of absolute difference of three models under A1B and A2 scenario will likely to be 46 and 49 days respectively. In comparison, with the base period, the mean of TR20 index showed an increase under two scenarios during 2011–2030. The mean of these changes compared to the base period is 13 and 11 days in A1B and A2 scenarios respectively. The percentages of changes in TR20 index during 2046–2065 under A1B and A2 scenarios show a significant increase. The mean of percentage of changes of three models are estimated 164 and 179%, under A1B and A2 scenario respectively. The absolute difference in this index for CNCM3, HadSM3 and NCCCSM models are 26, 32 and 36 days in A1B scenario respectively and 31, 32 and 40 days under A2 scenario respectively. The mean of the three models under A1B and A2 scenarios were estimated 32 and 34 days respectively. The percentage and level of changes in DTR extreme index during the two future periods are negligible. The results indicate that temperature indices of summer days (Tmax > 35 ∘C) and tropical nights (Tmin > 20 ∘C) are projected to increase, while DTR would have an insignificant increase. In both scenarios, all changes in two displayed temperature indices (SU and DTR) are significant, but the changes in A2 are generally more pronounced than in A1B. The projected difference in extreme temperature indices using NCCCSM outputs was estimated more than the other two GCMs. In Razavi Khorasan, a province of Iran dominated by an arid and semi-arid climate, significant climate anomalies is expected to occur in the future. These expected changes in extreme temperature indices will have a severe impact on living conditions, water supply, and agriculture in this region. This will demand socio-economic, agricultural and water management adaptation measures of this province.

5. Declarations

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Author’s Contribution

- **Mohammad Askari Zadeh** methodology, software and Collected the data,
- **GholamAli Mozaffari** supervision, designed the analysis and wrote the paper,
- **Mansoureh Kouhi** review and editing, revisions,
- **Younes Khosravi** review and editing, data analysis, software

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7. Tables

Table 4. The percentage of changes of SU35 in the stations during 2011-2030 and 2046-2065 (%)

2011-2030	SU35	Gonabad	Torbat-e-Heydarieh	Kashmar	Mashhad	Sabzevar	Sarakhs	Qochan	Golmakan
A1B	Base period (WG)	58.9	16.6	62.7	25.5	80.8	91.1	4.4	10.9
	CNCM3	74.8	32.1	77.3	46.0	102.7	104.5	8.8	18.9
	HadCM3	72.6	30.9	75.4	13.8	93.9	98.8	142.9	18.0
	NCCCSM	78.5	36.2	79.6	50.4	105.7	105.4	9.3	19.8
A2	CNCM3	70.5	25.5	72.4	39.3	98.3	101.6	8.8	15.7
	HadCM3	70.5	27.9	74.4	43.5	93.3	98.6	7.7	16.9
	NCCCSM	76.6	35.1	80.7	50.9	105.7	98	9.8	19.6
2046-2065	**SU35**	**Gonabad**	**Torbat-e-Heydarieh**	**Kashmar**	**Mashhad**	**Sabzevar**	**Sarakhs**	**Qochan**	**Golmakan**
A1B	Base period (WG)	58.9	16.6	62.7	25.5	80.8	91.1	4.4	10.9
	CNCM3	96.5	48.5	94.6	64.8	116.1	118.4	160.7	32.8
	HadCM3	101.0	56.1	97.7	72.6	117.5	120.7	160.4	39.9
	NCCCSM	105.4	62.1	102.5	78.0	122.0	122.5	23.2	43.1
A2	CNCM3	99.5	52.1	99.6	69.7	119.9	122.1	18.9	35.5
	HadCM3	101.6	55.6	99.2	72.2	117.8	119.7	21.5	39.8
	NCCCSM	107.8	67.1	106.0	81.5	123.2	125.0	26.0	46.9

Table 5. The percentage of changes of TR20 in the stations during 2011-2030 and 2046-2065 (%)

2011-2030	TR20	Gonabad	Torbat-e-Heydarieh	Kashmar	Mashhad	Sabzevar	Sarakhs	Qochan	Golmakan
A1B	Base period (WG)	65.5	23.2	83.0	19.2	77.5	70.7	5.6	5.6
	CNCM3	79.0	38.1	94.4	32.9	97.3	85.7	4.0	9.8
	HadCM3	78.5	36.2	94.2	29.8	93.7	81.7	2.3	9.5
	NCCCSM	81.1	41.0	96.3	34.7	99.7	86.6	4.3	9.7
A2	CNCM3	75.5	32.0	91.7	27.6	93.0	82.1	7.8	7.8
	HadCM3	76.1	33.8	93.5	27.6	92.4	81.1	3.3	8.2
	NCCCSM	82.1	42.3	96.0	34.9	100.4	82	4.4	10.2
2046-2065	**TR20**	**Gonabad**	**Torbat-e-Heydarieh**	**Kashmar**	**Mashhad**	**Sabzevar**	**Sarakhs**	**Qochan**	**Golmakan**
A1B	Base period (WG)	65.5	23.2	83.0	19.2	77.5	70.7	5.6	5.6
	CNCM3	97.5	52.5	110.7	45.2	111.3	101.8	9.0	18.0
	HadCM3	101.5	58.0	112.5	51.3	112.8	103.1	14.0	22.8
	NCCCSM	104.2	61.6	116.3	55.7	116.8	106.8	14.2	24.4
A2	CNCM3	101.1	54.8	115.2	49.7	116.2	105.6	20.02	20.0
	HadCM3	102.1	58.6	112.9	51.6	113.3	104.1	14.1	22.9
	NCCCSM	108.5	65.5	119.3	59.5	119.5	108.4	16.4	26.7

Table 6. The percentage of changes of DTR in the stations during 2011-2030 and 2046-2065 (%)

2011-2030	DTR	Gonabad	Torbat-e-Heydarieh	Kashmar	Mashhad	Sabzevar	Sarakhs	Qochan	Golmakan
A1B	Base period (WG)	13.0	13.8	11.8	13.8	13.6	13.6	13.5	13.7
	CNCM3	13.1	13.8	11.8	13.8	13.6	13.6	13.5	13.7
	HadCM3	13.1	13.9	11.7	13.8	13.5	13.6	12.1	13.7
	NCCCSM	13.1	13.8	11.8	13.9	13.6	13.6	13.5	13.7
A2	CNCM3	13.1	13.8	11.8	13.9	13.6	13.6	13.5	13.7
	HadCM3	13.0	13.8	11.8	13.8	13.5	13.6	13.6	13.7
	NCCCSM	13.1	13.8	11.8	13.9	13.5	13.5	13.6	13.7
2046-2065	**DTR**	**Gonabad**	**Torbat-e-Heydarieh**	**Kashmar**	**Mashhad**	**Sabzevar**	**Sarakhs**	**Qochan**	**Golmakan**
A1B	Base period (WG)	13.0	13.8	11.8	13.8	13.6	13.6	13.5	13.7
	CNCM3	13.1	13.8	11.8	13.9	13.5	13.6	13.5	13.7
	HadCM3	13.1	13.8	11.8	13.9	13.6	13.6	13.5	13.7
	NCCCSM	13.1	13.8	11.8	13.9	13.6	13.6	13.5	13.7
A2	CNCM3	13.1	13.8	11.9	13.8	13.6	13.6	13.52	13.7
	HadCM3	13.1	13.8	11.8	13.8	13.5	13.6	13.5	13.7
	NCCCSM	13.1	13.8	11.8	13.9	13.5	13.6	13.6	13.7

Figures

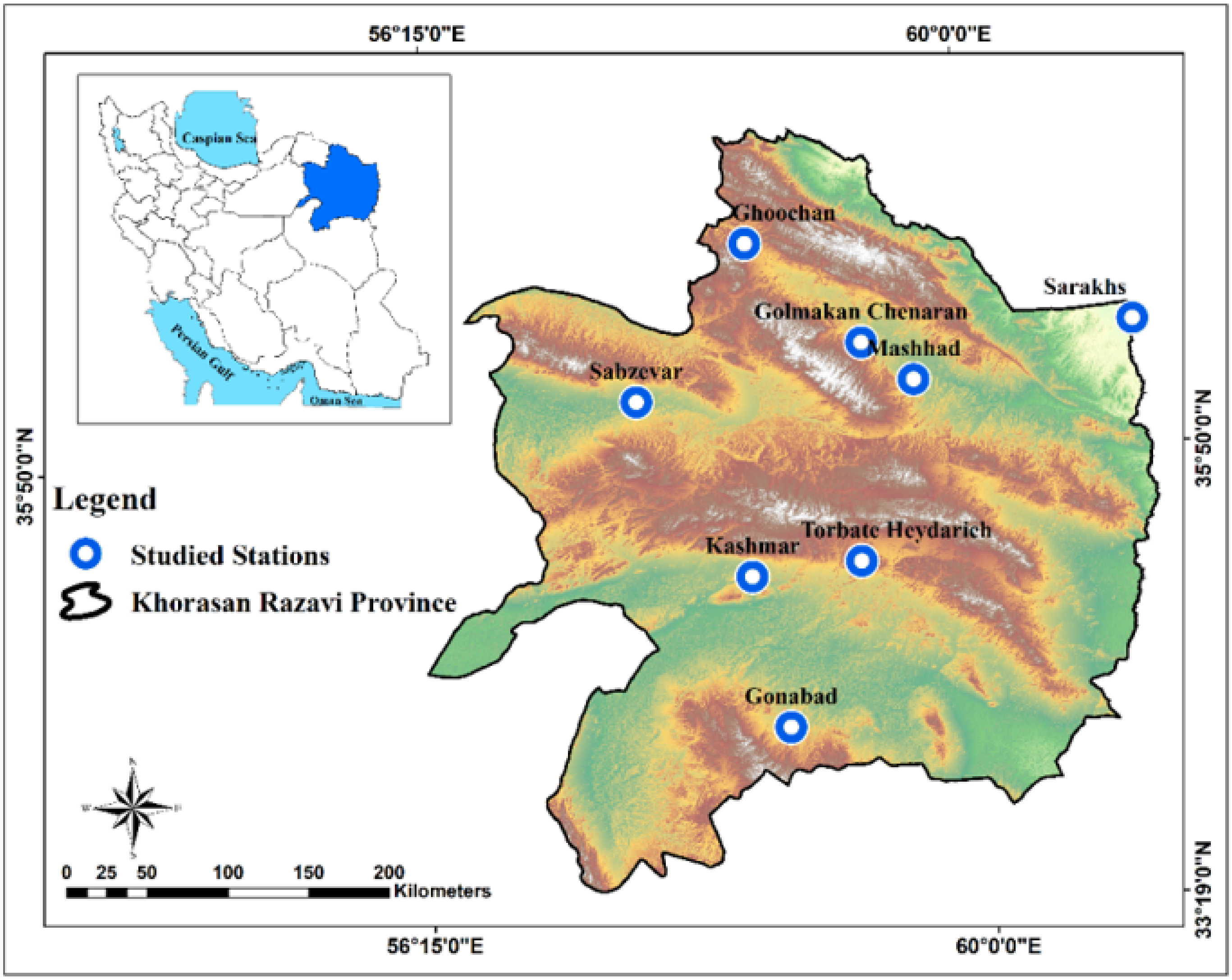

Figure 1

Location of study area and distribution of stations under study

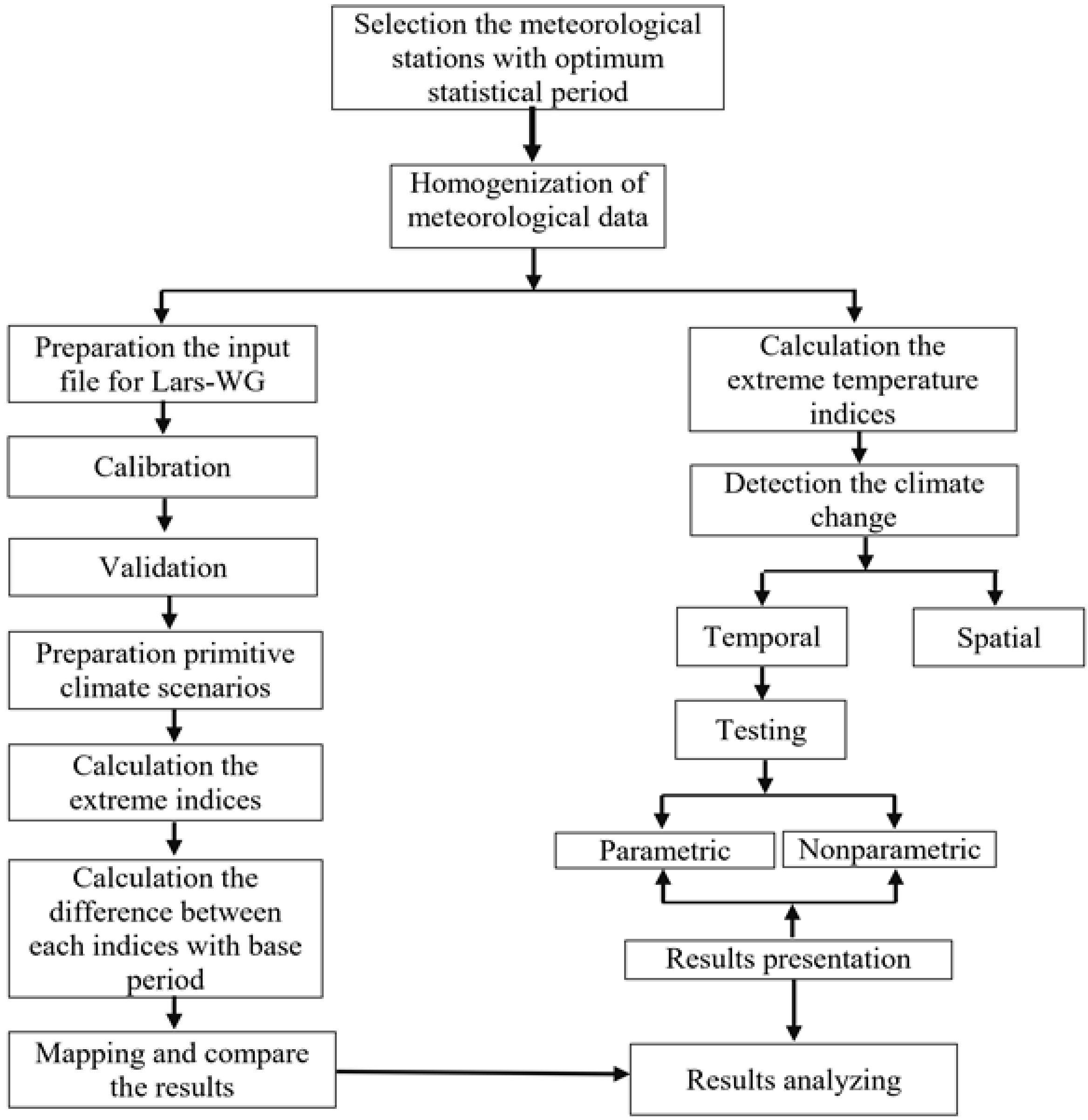

Figure 2

Research methodology Flowchart

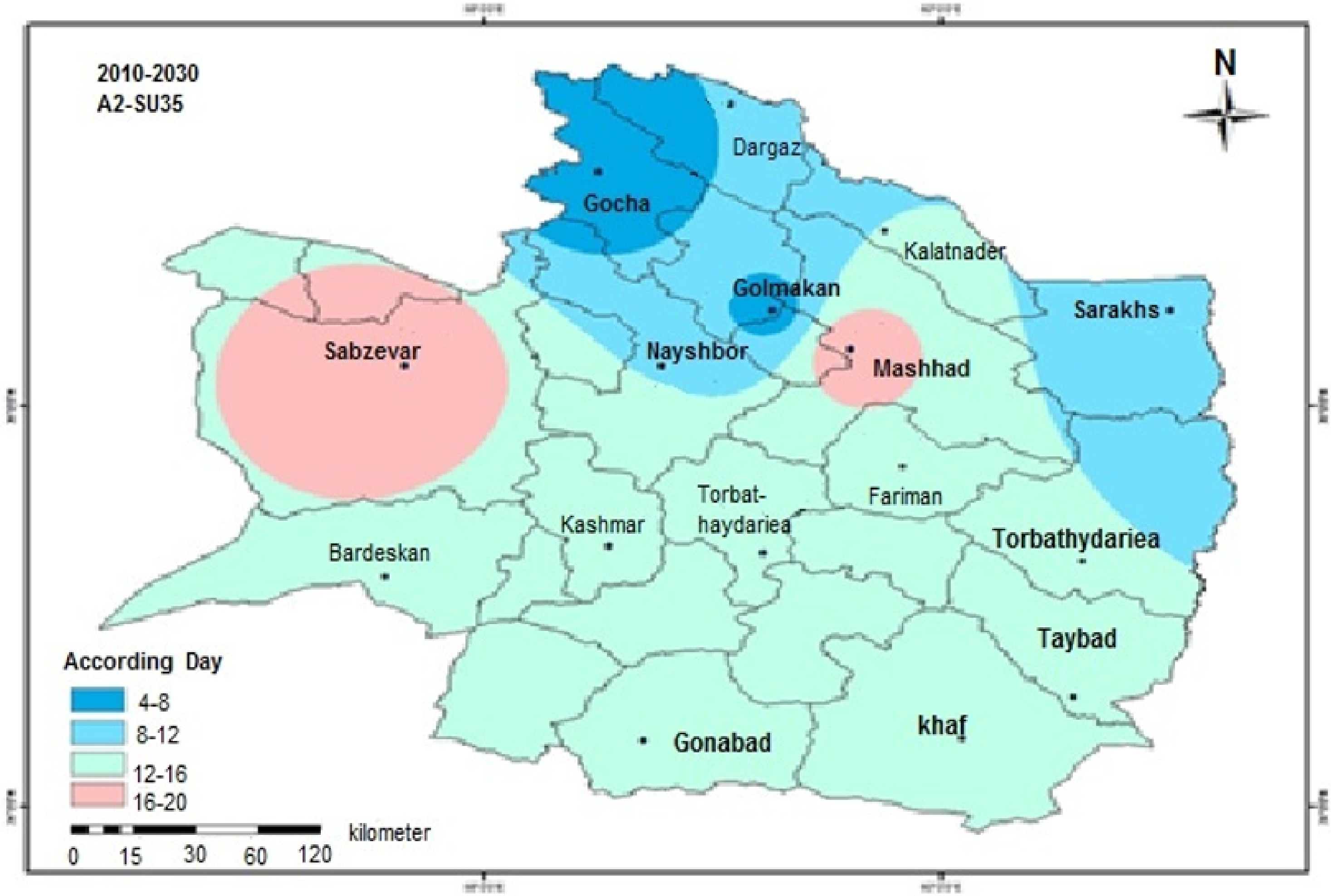

Figure 3

Spatial distribution of extreme index of SU35 according to A2 scenario during 2011-2030 over Razavi Khorasan province

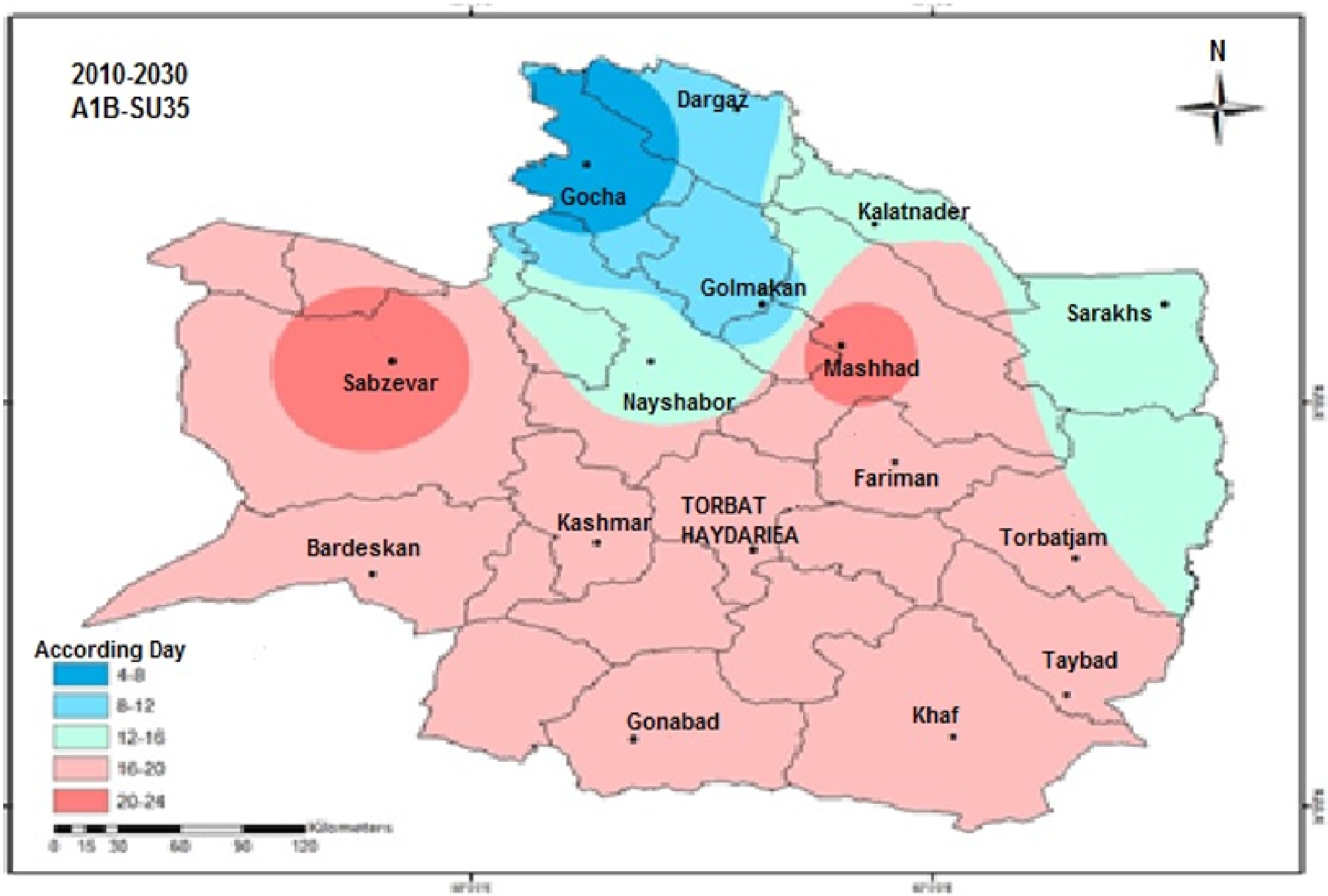

Figure 4

Spatial distribution of extreme index of SU35 according to A1B scenario during 2011-2030 over Razavi Khorasan province

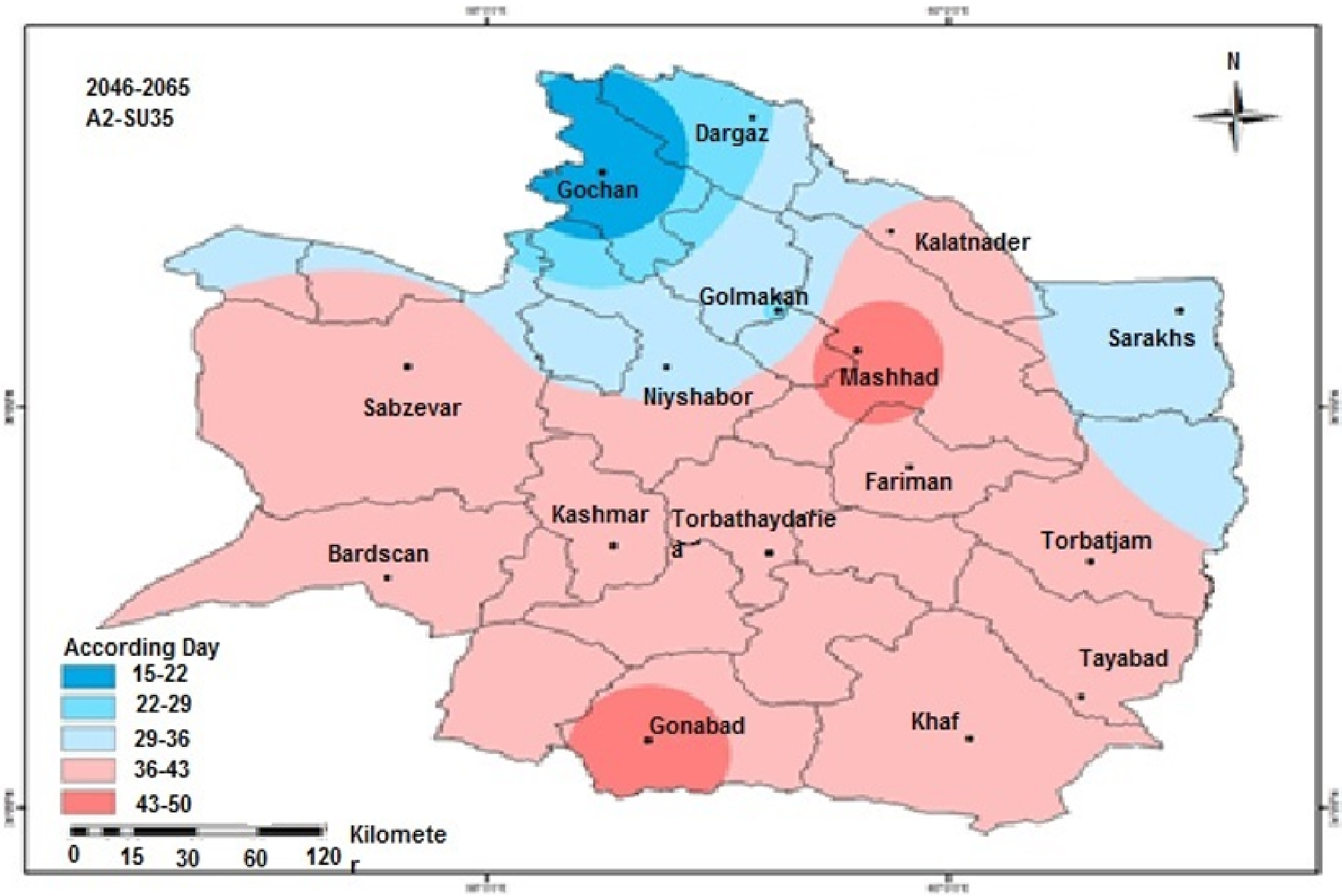

Figure 5

Extreme index of SU35 distribution according to A2 scenario 2046-2065 over Razavi Khorasan province

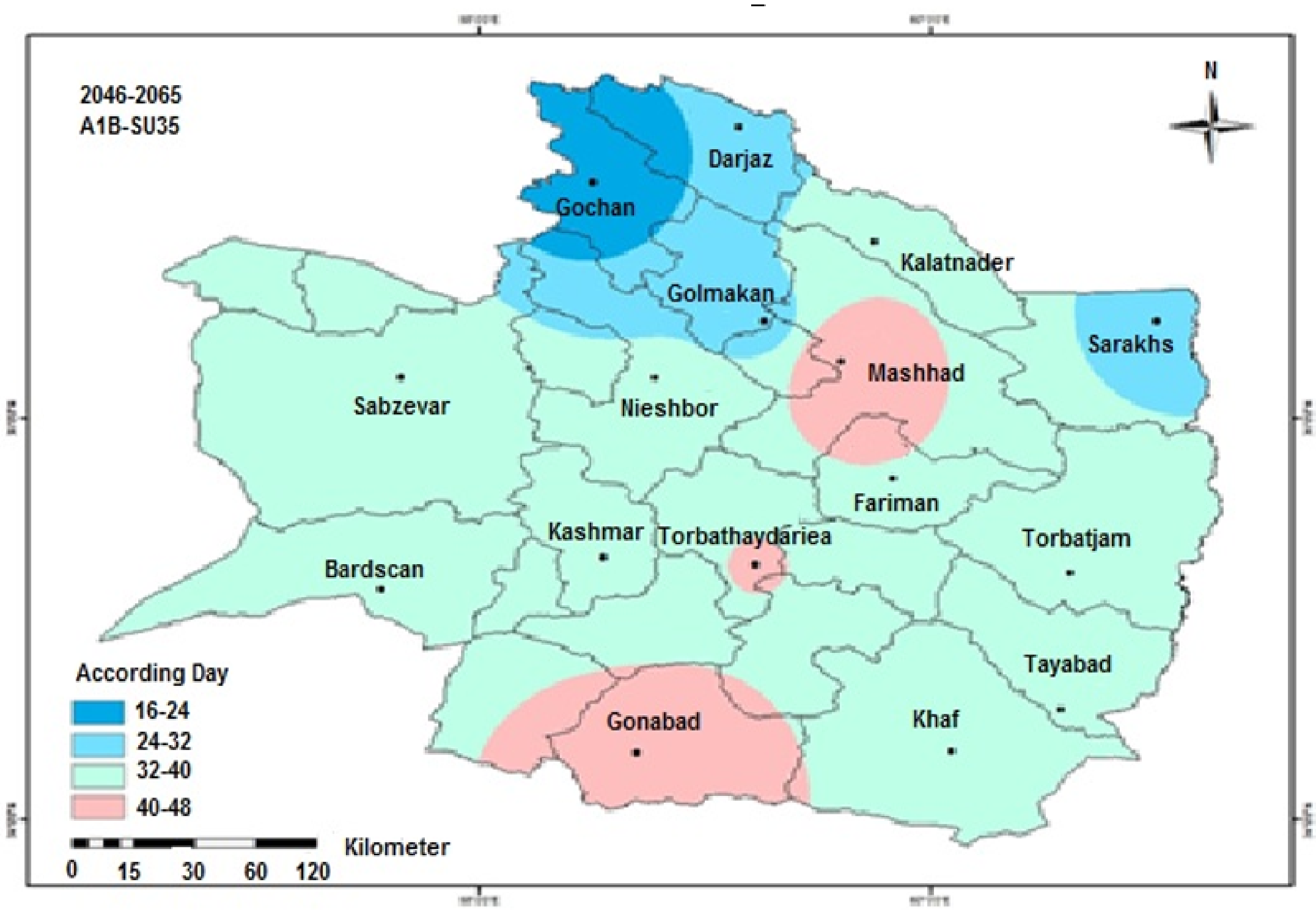

Figure 6

Extreme index of SU35 distribution according to A1B scenario 2046-2065 over Razavi Khorasan province