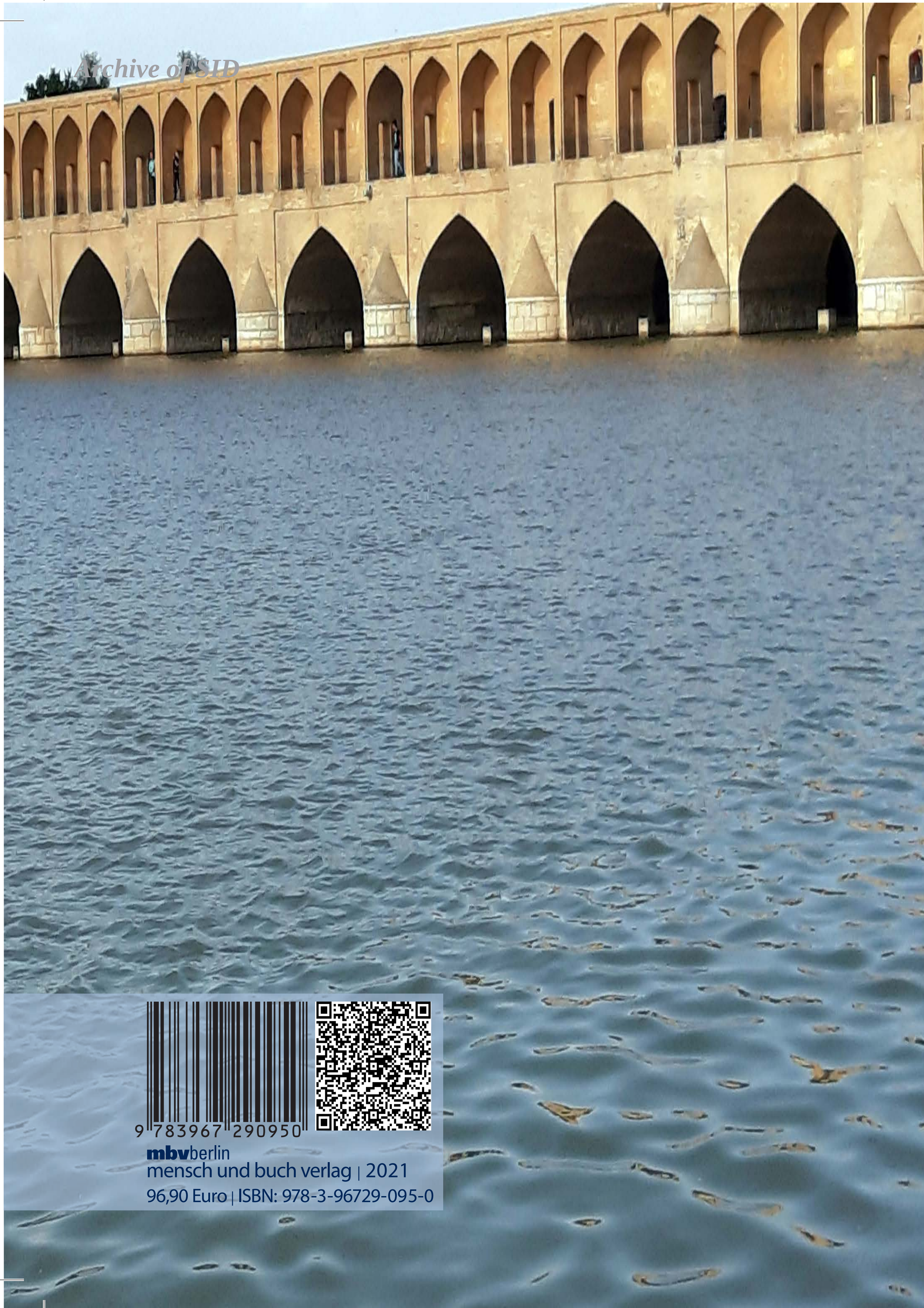

9 783967 290950
mbvberlin
mensch und buch verlag | 2021
96,90 Euro | ISBN: 978-3-96729-095-0

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Responding Challenges of Climate Change through Intercultural Dialogue

Mais Jafari - Dietwald Gruehn
Hasan Sinemillioglu - Mathias Kaiser (Hrsg.)

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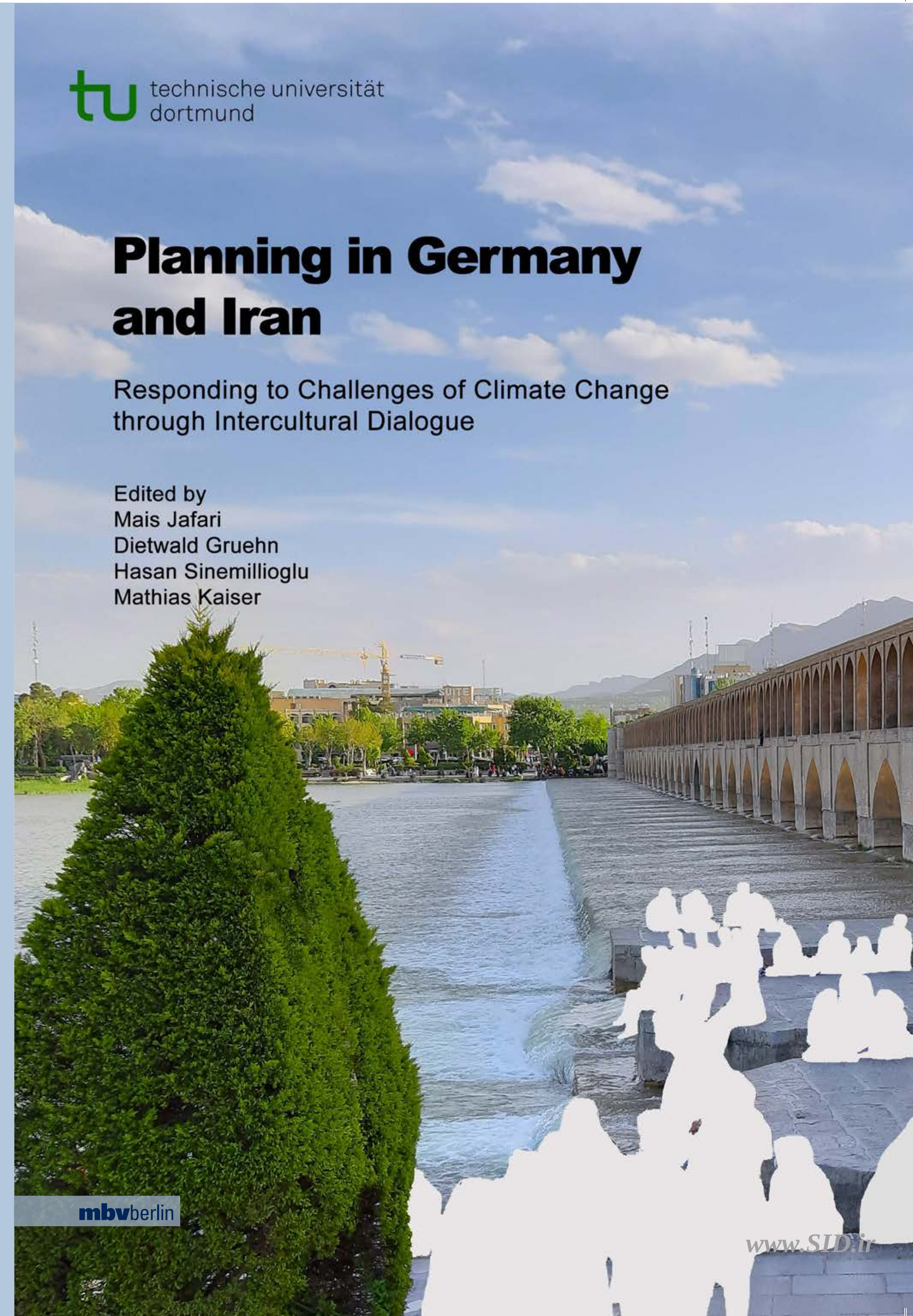

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عنوان :

بررسی اثرات تغییر پارامترهای اقلیمی بر منابع آب بالادست حوضه آبخیز زاینده رود

Investigating the Effects of Climate Parameters Change on Upstream Water Resources of Zayandehrud Watershed

گروه تخصصی: فنی مهندسی

سازمان مجری :دانشکده معماری و شهرسازی مؤسسه آموزش عالی دانش پژوهان پیشرو و دانشکده برنامه ریزی فضایی دانشگاه صنعتی دورتمند آلمان

نوع طرح: پروژه مشترک با دانشگاه صنعتی دورتمند حمایت شده توسط مرکز تبادلات آکادمیک آلمان (DAAD) در چهارچوب برنامه Higher Education Dialogue with Islam World

پژوهشگران :

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میرزایی مژگان (همکار طرح)

تاریخ خاتمه: ۱۳۹۹

کارفرما :دانشگاه صنعتی دورتمند آلمان و مؤسسه آموزش عالی دانش پژوهان پیشرو

خروجی طرح : کتاب: برنامه ریزی در آلمان و ایران - پاسخگویی به چالش‌های تغییر اقلیم از طریق گفتگوی میان‌فرهنگی
Planning in Germany and Iran - Responding to Challenges of Climate Change through Intercultural Dialogue

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تلفن: ۱۹-۰۳۱-۳۷۷۷۹۹۱۴

نشانی سازمان مجری : اصفهان، بلوار کشاورز، نبش چهارراه مفتح

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This publication has been funded by the DAAD
German Academic Exchange Services

DAAD Deutscher Akademischer Austausch Dienst
German Academic Exchange Service

Bibliografische Information der *Deutschen Nationalbibliothek*
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <https://dnb.de> abrufbar.

ISBN: 978-3-96729-095-0

Umschlagabbildung | Umschlaggestaltung: Mais Jafari

 Choriner Str. 85 - 10119 Berlin
verlag@menschundbuch.de – www.menschundbuch.de

2.

Investigating the Effects of Climate Parameters Change on Upstream Water Resources of Zayandehrud Watershed

Sadat Hashemi Nasab, Amir Masoud Samani Majd, Bryce Timothy Lawrence, Mojgan Mirzaei

Abstract

Increasing or decreasing rainfall over long-term average conditions causes two major phenomena: flood and drought. Drought, rising temperatures, rising consumption, and improper management patterns are fundamental causes of the water crisis that pose a serious threat to the human future. One of the effects of climatic parameters change is the occurrence of water stress. This threat is much more acute in aquatic watersheds (arid regions), particularly in central Iran. Therefore, evaluation, simulation, and prediction of this phenomenon are of great importance in the future due to its consequences on water resources and their effects on the political, social, and economic relations of societies.

The purpose of this study was to evaluate the relationship between climatic parameters and their effects on surface and groundwater resources upstream of the Zayandehrud watershed. Firstly, using the annual precipitation data of Fereydunshahr and Daran stations during the past statistical period, Standardized Precipitation Index (SPI) and its effect on surface and groundwater resources from 1991 to 2011 were evaluated. Then, the minimum and maximum temperature parameters from the CORDEX dataset and RCP4.5 scenario until 2040 were scaled and predicted. The results of this study showed that 2008 was one of the driest years in the upstream watershed. It was also found that precipitation affected the surface and subsurface water of this part of the watershed. Estimates of minimum and maximum temperature data indicate an increase in the upstream area of the watershed, especially during winter. The threshold for incremental changes will be between 0.2 and 2.6 ° C.

Keywords: Drought, Climate change, Water resource, GCM, Zayandehrud watershed

1. Introduction

Human society is at a critical juncture in history. The increasing destruction of resources, the emerging imbalance of the life cycle, the growing population, hunger, poverty, and the destruction of the ecosystems on which human life now and in the future depend, threaten everyone. The amount of drinking water for humans is itself limited, and only about 2.53 percent of the total water available in the world is in the form of freshwater, of which only 30.11 percent is in the form of groundwater and 0.01 percent in the form of rivers (IRWC, 2011). Therefore, very little of this amount is available to human beings. As a result of this shortage, the occurrence of water stress due to climate change such as rising temperatures, drought, and reduced snow cover are some of the major challenges in the world. It can affect the discharge of rivers in different parts, especially upstream. And as the world's climate changes and global warming occurs (Dracup and Vicuna, 2005: 483), declining water supply of underground aqueducts (Qantas), springs and water wells will follow. The following are some of the studies that have been done on climate change and its effects on water resources in different regions.

Alcamo et al. (2000) used BAU[1], TEC[2] and VAL[3] scenarios in global climatic models and linked them to hydrological models to show that the fragile conditions of the world's water resources will continue, at least until 2025. Areas with acute water stress will increase from 36.4 to 38.6 million square kilometers, and this water stress will be more acute in the south and west of Africa and Asia. Serrano et al. (2005) compared the hydrological reaction at different time scales of climatically-induced drought using the Standardized Precipitation Index (SPI) to identify droughts in usable water resources. Steele-Dunne et al. (2008) examined the effect of climate change on the hydrology of watersheds in the Netherlands using the ECHAM5 general circulation model and the A1B emission scenario. The results of their studies showed that winter precipitation increased and summer precipitation decreased and this will lead to a change in fluvial discharge regimes. Lisa and Julie (2009) examined the trend of extreme climatic conditions in Australia. The results showed that temperature fluctuations (especially heat waves and the number of tropical nights), long dry periods (scattered throughout the year), and extreme rainfalls had increased significantly.

[1]- Business-As-Usual
[2]- Technology, Economics and Private Sector
[3]- Values and Lifestyles

Dalfardi and Basari (2009) predicted the probabilities of drought and wet periods for the inflow to the Lar Dam, in Iran, using the Markov chain. The results showed that the probability of drought in the upper region of the Lar Basin is 90.8% and the probability of occurrence of a wet period is 6.1%. Santos et al. (2010) examined the trend of daily extreme temperature and precipitation indices in Utah, USA in 28 stations ranging from 1930-2006, showing that despite the decreasing trend of precipitation, temperature and precipitation extremes increase. Analyzing long-term changes, Schlunzen et al. (2010) identified positional differences in temperature and precipitation around the metropolis of Hamburg, Germany. The average temperature in Hamburg has also increased significantly during the statistical period of 1891-2007 (0.77 degrees Kelvin), 1948-2007 (0.2 degrees Kelvin) and 1978-197 (0.6 degrees Kelvin), with the most significant increase in temperature observed in autumn.

Martinez et al. (2010) examined the minimum and maximum temperature trends with the help of data from 37 stations in Catalonia, Spain, during the statistical period 1975-2004. The results showed that the annual temperature increased by 0.5 °C in each decade (spring and summer), up to 0.8 to 0.9 °C in winter. Leong Tan et al. (2017) examined the effects of climate change in the Kelantan watershed in Malaysia under the CMIP5 model and RCPs scenarios with the SWAT semi-distributed model. Based on the output of CMIP5 model, it was determined that the annual amount of precipitation during the period of 2015-2044 would increase between 1.2 to 8.7% and the maximum temperature will increase from 0.6 to 1.2 °C. Annual flow rates will also increase by 27.2 %.

Masah Bouani and Morid, (2005) and Masah Bouani (2006) examined the effects of climate change on the Zayandehrud using the HadCM3 model. Their results showed that by 2100, the average temperature would increase between 4.6 and 3.2 °C and the amount of precipitation and inflow of Zayandehrud Dam will decrease by 5.8. The results of studies by Zahabioon et al. (2010) show an increase of 1 to 4 °C in temperature, a decrease of 20 to 30% in precipitation, and a change of 9 to 12 percent decrease in the discharge of Qarreh Soo River. From the category of hydrological drought studies in different regions of Iran, we can mention research by Shamsipoor (2003: 115), Azizi (2003: 131), Shakiba et al. (2009: 119), Behnianfar (2010: 53), Ghobadi et al. (2014: 66), Raqibi et al. (2017: 20), Saboohi (2019), Mirzaei (2019), Ahmadi (2019), and Maleki et al. (2015: 65). Most researchers have agreed on rising temperatures, precipitation fluctuations and their effects on water resources.

Both upstream and downstream areas of Zayandehrud watershed, composed of different climate groups, sub-groups and sub-divisions, has not been unaffected by the drought, especially since climate parameter changes in the upstream parts of the watershed are more intensive given the change from a humid D and C climate group to the arid and semi-arid B climate group. Therefore, it is necessary to study these conditions and pay attention to them for planning and management of water resources in the coming years, considering the emerging changes. The main purpose of this study is to evaluate the change of climatic parameters and their effect on upstream water resources in the previous period and then project these changes over a long-term planning horizon.

1.1 Location of the study area

Zayandehrud basin (Figure 2-1), with an area of 27,000 square kilometers, includes most of the Gavkhuni watershed, which is part of the Central Desert watershed. Zayandehrud watershed is bounded on the north by Namak Lake watershed, on the west and southwest by Karun and Dez watersheds, on the east by Daqq-e Sorkh and Shah Kooh Desert watersheds, and on the south by Shahreza watershed. The highest point is Karbush Mountain, with a height of 3974 meters above sea level and the lowest point is Gavkhuni Wetland, with a height of 1450 meters above sea level. Climate change in this watershed is very significant, trending from cool deserts (BWk) to hot desert (BWh) at lower elevations and from snow microthermal climates (Dsa) (Raziei, 2017). While in the Chelgerd area in the west, the watershed has precipitation more than 1400 mm, the east of the watershed, next to Gavkhuni Wetland, has a precipitation of 100 mm. About 93% of the area of this watershed is in Esfahan province and only 7% is in Chaharmahal and Bakhtiari (IRWC, 2011: 3).

Zayandehrud is the most important and water-rich river in the Gavkhuni watershed, located in Esfahan province. Zayandehrud, which originates from Zardkooh in Bakhtiari province, is one of the most important rivers in Iran and also the most water-rich river in the central Iranian plateau. The average annual flow of the river is about one billion m^3/S. The water of this river mainly comes from the upland snow that falls in the cold seasons of the year. The source of this river is at an altitude of 2200 meters in Rizabeh Chamdar and Abzari, which originates with the water of Koohrang tunnel located in Karkonan Mountain behind Poshtkuh Mogouei village, Frieden city, and 64 km southwest of Daran. Zayandehrud flows south after crossing the Zayandehrud Dam Lake and enters Chadegan village. After a distance of about 405 km and passing through many villages and cities of Esfahan province, this river finally flows into Gavkhuni wetland in the south of Siah Mountain, located 123 km southeast of Esfahan and 29 km southeast of Varzaneh city.

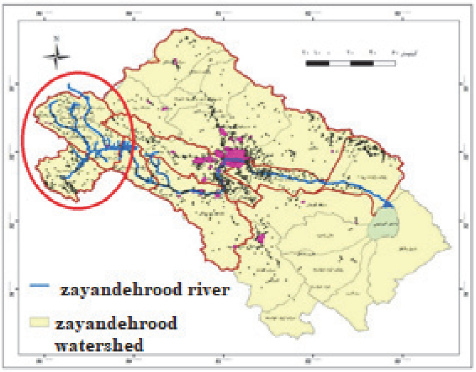

Figure 2-1 Location of Zayandehrud watershed and its upstream stretch

2. Materials and methods

In this study, 22-year precipitation data of Fereydunshahr (climatology) and Daran (synoptic) stations during the 1991 to 2011 period have been used. The daily precipitation data was first converted from the Gregorian format to the Hijri water year, and statistical gaps were calculated using surfer software as the base cell at the desired stations. Then, surface and groundwater data were prepared and arranged on a daily basis from 1991 to 2012. Then, the SPI indicators were calculated using DIP software and the years were evaluated. Then, the surface and groundwater changes in the wells of the mentioned areas were measured. After that, the minimum and maximum temperature and precipitation of CORDEX series models (Riahi & et al. 2011) based on CMIP5 and RCP4.5 scenarios (Moss et al. 2010) were extracted and downscaled. These models use new RCPs scenarios, including RCPs of 2.6, 4.5, 6 and 8.5 (Moss et al. 2010), which aim to provide a set of information from which the main causes of climate change can be traced and applied to climate models. The scenarios are based on different SRES scenarios (Nakicenovic et al., 2000) that characterize the level of technology, social and economic status, and future policies that can lead to different outcomes of greenhouse gas emissions and climate change. In each version of these scenarios, the effect of greenhouse gas emissions, based on its role on the level of radiative forcing, is divided into four categories and is projected up to the end of the 21st century. The results of these scenarios also cover the period from 1850 to the end of the 21st century and are also projected until 2300.

The variables in these scenarios are:

- CO_2, CH_4, N_2O, HFCs, PFCs, CFCs, SF_6 emission rates
- The emission rates of active chemical gases and aerosols, and black carbon (soot, SO_2, organic carbon, CO_2, Nox, VOCs, NH_3)
- Concentrations of greenhouse gases CO_2, 4 CH, N_2O, HFCs, PFCs, CFCs, SF_6
- The concentration of aerosols and active chemical gases O_3, aerosol.
- Land use data and land surface coverage.

In this study, using the RCP4.5 scenario, the CO_2 concentration until 2100 is estimated at PPM650 and the effect of greenhouse gases on radiative forcing is estimated at 4.5 watts per square meter. The RCP4.5 scenario represents the maximum CO_2 emission around 2040 and decreases afterward, and the RCP8.5 shows an increase until the end of the 21st century. The dimensions of this database's cells are 0.4 (latitude) * 0.4 (longitude), which were upgraded to 0.25*0.25 degree by applying the Kriging interpolation method in MATLAB software. The desired output was extracted for the desired stations according to the RCP4.5 scenario (Figure 2-2).

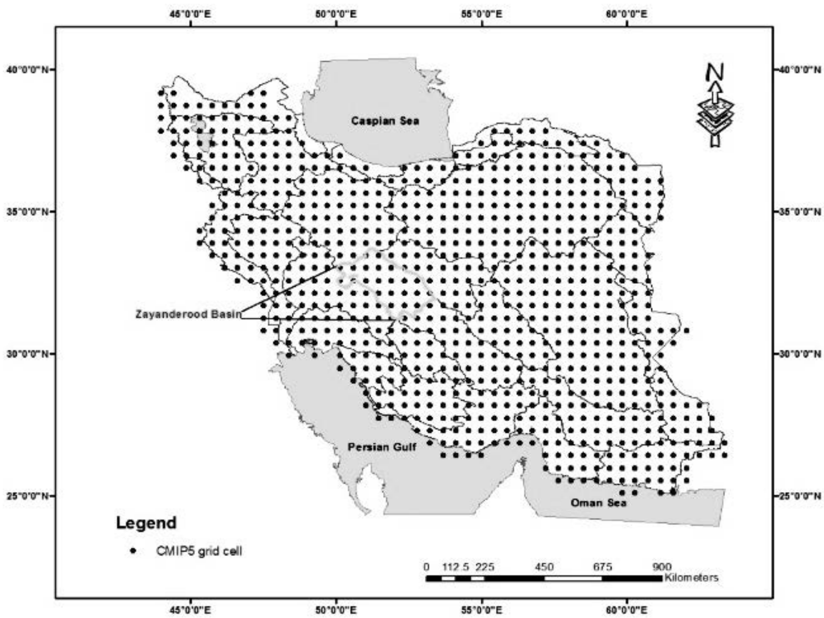

Figure 2-2 Position of the fifth report output in the study area

3. Results and discussion

The upstream Zayandehrud watershed has a large portion of Esfahan province's water resources so that most of it is discharged as surface water by the Zayandehrud river and is transferred to the central and eastern areas of the province and then to other provinces. With population centers, lands prone to the construction of industries in the upstream parts of the watershed, and due to the rapid transfer of water from this region, the use of groundwater resources is necessary to compensate for shortages of water resources. More than half of the water needs in the basin are met via groundwater extractions. Meteorological droughts occurred during the statistical period in the study stations and the numerical value of each index was calculated.

Daran Station has a winter precipitation regime with an average rainfall of 333.6 mm. The lowest amount of precipitation occurred in 2008 with 129.6 mm, and the highest amount of precipitation occurred in 1993 with 50.9 mm. After that, 2006 with a value of 48.81 mm, was in the second most rainfall in the years of study. In total, during 12 years, the rain at this station; was more than the average and for 10 years was less than the average rainfall. Evaluating the SPI index revealed that during the water year of 2008, drought was more severe and became extremely dry. During the year 2000, severe dry conditions also occurred (Table 2-1). In contrast, the wet period occurs noticeably, and in most years, it experiences a near-normal state, and in some years, a mild dry state is observed. Fereydoonshahr, same as Daran, has a regime of winter precipitation. The average precipitation of this station is 578 mm. The lowest precipitation in this region was recorded in 2008 with 294.6 mm and the highest precipitation recorded in 1993 with 101.91 mm. The year 2006 recorded the amount of 759 mm, the second-highest precipitation in the studied years. In fact, this zone has experienced greater than average rainfall over 12 years and less than average for 10 years. The SPI index also showed that Fereydoonshahr had passed the severely dry conditions in years of 2008 and 1999 and in 1993 had extremely wet conditions.

Table 2-1 Conditions of SPI index outputs on the upstream areas of Zayandehrud watershed

Fereydoonshahr				**Daran**			**Stations**
SPI	Year	SPI	Year	SPI	Year	SPI	Year
Near normal	2002-2003	Near normal	1991-1992	Near normal	2002-2003	Near normal	1991-1992
Near normal	2003-2004	Extremely wet	1992-1993	Near normal	2003-2004	Moderately wet	1992-1993
Near normal	2004-2005	Near normal	1993-1994	Near normal	2004-2005	Near normal	1993-1994
Moderately wet	2005-2006	Near normal	1994-1995	Moderately wet	2005-2006	Near normal	1994-1995
Moderately wet	2006-2007	Near normal	1995-1996	Near normal	2006-2007	Near normal	1995-1996
Extremely dry	2007-2008	Near normal	1996-1997	Extremely dry	2007-2008	Moderately dry	1996-1997
Near normal	2008-2009	Near normal	1997-1998	Near normal	2008-2009	Near normal	1997-1998
Near normal	2009-2010	Extremely dry	1998-1999	Near normal	2009-2010	Moderately dry	1998-1999
Near normal	2010-2011	Moderately dry	1999-2000	Near normal	2010-2011	Extremely dry	1999-2000
Near normal	2011-2012	Moderately dry	2000-2001	Near normal	2011-2012	Moderately dry	2000-2001
Near normal	2012-2013	Near normal	2001-2002	Near normal	2012-2013	Near normal	2001-2002

According to table 2-1, Daran station has spent 68.1% of the studied years in the near-normal condition, 22.7% of the years in the dry condition with different degrees, and 9% of the years in the wet period condition. Fereydunshahr had 13.6% wet period conditions and 18.1% drought of varying degrees.

By examining the flow of Zardfahrah River, which is located in the watershed of Fereydunshahr, we find that discharge follows the SPI index. In drought periods such as 1994, 1997, 1999 to 2001, and especially in 2008, river discharge also declines. In wet periods of 1993, 1995, 1998, 2001, and 2006 also showed an increase in discharge, which indicates the great impact of drought on the Zardfahrah River. In summary, we find that the increasing and decreasing discharge trends of the Zardfahrah river have always fluctuated and followed the SPI index patterns of wet and drought conditions (Figure 2-3).

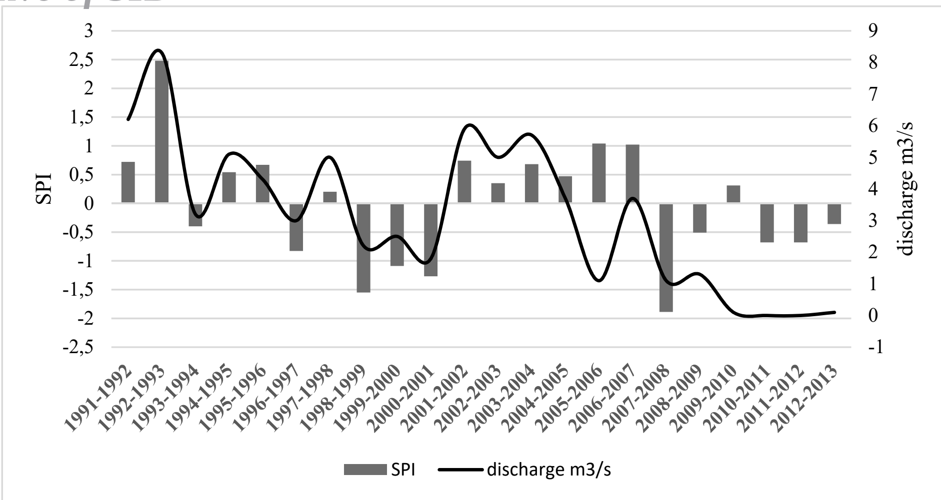

Figure 2-3 Investigating the surface flow of the Zardfahrah with the SPI index

Langan spring is also located in Fereydunshahr watershed. The discharge of this region also visibly reflects the SPI index. During the droughts of 1994, 1997, 1999 to 2001, and especially in 2008 due to the severe intensity of drought, discharge declined considerably. Significant reduction in discharge is also visible in recent years, likely due to precipitation reduction, agricultural consumption, and redirect river flow, resulting in the Langan spring almost completely drying up. In wet periods of 1993, 1995, 1998, 2004, and 2006, there was an increase in discharge, indicating a connection between rainfall volume and discharge rate (Figure 2-4).

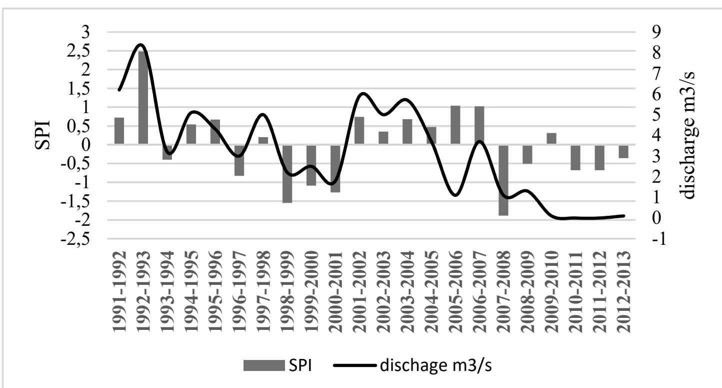

Figure 2-4 Investigating the surface flow of Langan spring with SPI index

In Daran region, the discharge of Hassanabad River generally reflects the level of recipitation (Figure 2-5).

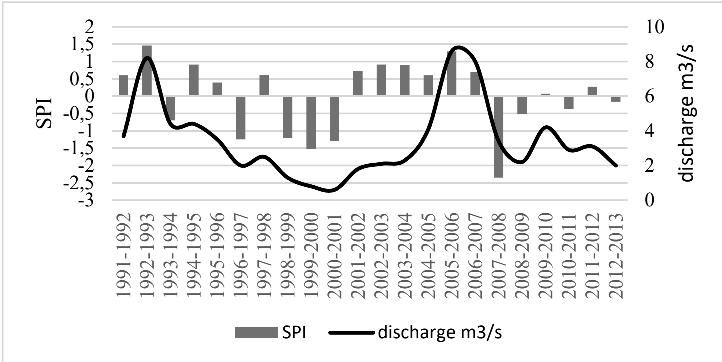

Figure 2-5 Investigating the surface flow of Hasanabad with SPI index

Extracted statistics from the depth of well water close to Daran station, including Nanadegan, Namagard, Chigan, Moghan, Ganjeh, south of the Khalaj and Seftjan rivers, showed that all of the wells had a slight decline in the early 2000s and during the water year of 2008 suffered from severe water shortage, recording the lowest water level during this year. In 2010, due to near-normal precipitation conditions, modification of consumption patterns and prevention of intense harvest, the situation improved. However, again in late 2012, critical conditions arose due to low precipitation and people's need for water (Figures 2-6 and 2-7).

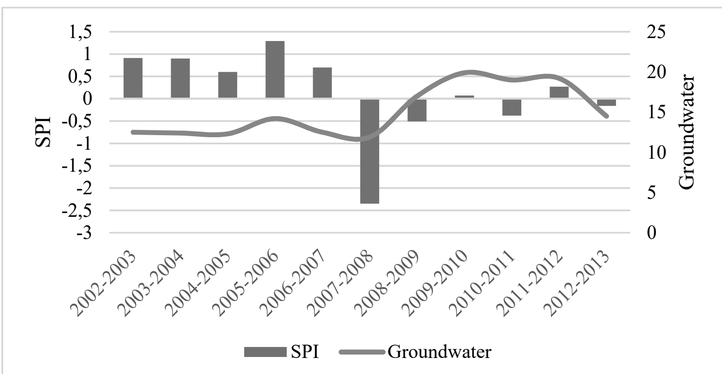

Figure 2-6 The compatibility of Depth of well water (Nanadegan) with the SPI index

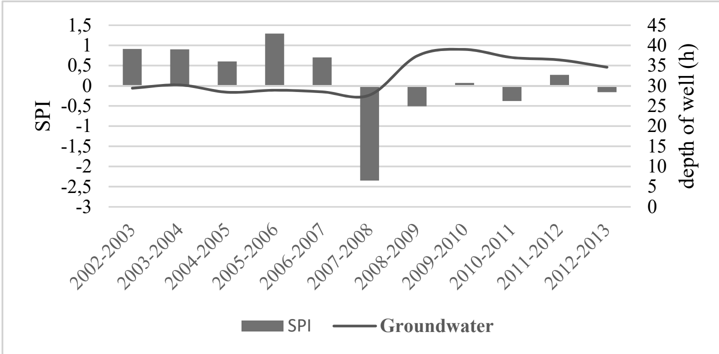

Figure 2-7 The compatibility of Depth of well water (Chigan) with the SPI index

In Fereydunshahr region, by examining the water wells of Khameslu, West of Sangbaran, Sorshojan, Dehsour, Chafa, Sadeghieh, Badjan of Fereydunshahr and Bazmeh, the drought index was evaluated. The output results showed the impact of drought conditions on the depth of groundwater, especially the SPI intensity in 2008 was obvious. Examining the upstream areas of the Zayandehrud watershed, it can be acknowledged that changes in precipitation over the years of study have had a significant effect on the flow rate and the depth of groundwater. These conditions have been accompanied by a sharp decline in discharge over the years and a corresponding drop in aquifer levels (Figure 2-8 – 2-11).

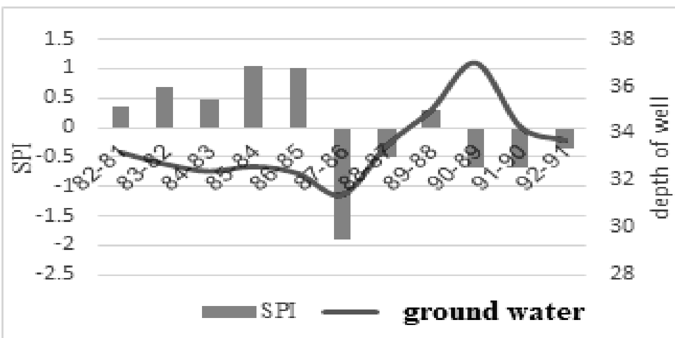

Figure 2-8 Compatibility of groundwater (Khameslu) with SPI index

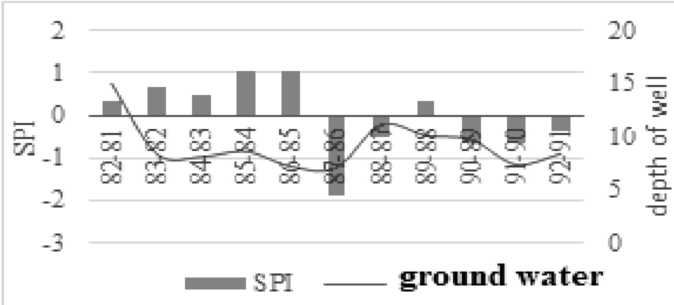

Figure 2-9 Compatibility of groundwater (west of Sangbaran) with SPI index

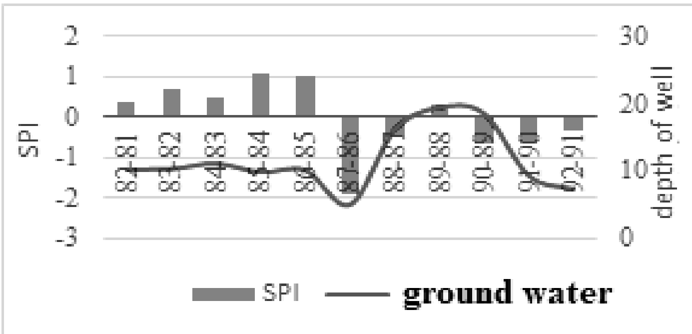

Figure 2-10 Compatibility of groundwater (west of Sangbaran) with SPI index

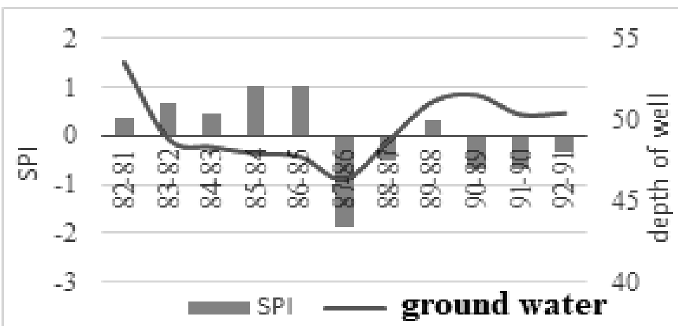

Figure 2-11 Compatibility of groundwater (Chafa) with SPI index

In the next step, using the coefficient of determination (R), Root Mean Square Error (RMSE), and the Mean Absolute Error (MAE), the data generated by the model and the actual (observational) data were evaluated (citation for R, RMSE, MAE needed).

Equation (1) $$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x}).(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2.\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Equation (2) $$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_{obs,i} - x_{\mathrm{mod}el,i})^2}{n}}$$

Equation (3) $$MAE = \frac{\sum_{i=1}^{n}\left|X_{obsi} - X_{\mathrm{mod}eli}\right|}{n}$$

Regarding the coefficient of determination, the closer the calculated number is to one, the better the simulation of the model (Khalili et al., 2006).

Table 2-2 Measurement of monthly minimum temperature output above Zayandehrud watershed

Fereydoonshahr	Daran	Stations
0.99	0.99	**R**
0.97	0.63	**RMSE**
0.079	0.136	**MAE**

Table 2-3 Measurement of monthly maximum temperature output above Zayandehrud watershed

Fereydoonshahr	Daran	Stations
0.99	0.99	**R**
0.824	1.012	**RMSE**
0.15	0.117	**MAE**

According to the above tables and the results of statistical tests on climatic data, it was determined that the downscaling output of the CORDEX dataset has the ability to simulate climatic variables for the future. Then, in order to change the field of GCM data, the output of these models that have been executed for the previous period and the measured data in the same statistical period are used, and adjustments are made to match the statistical characteristics (such as the mean) of the GCM data with the statistical characteristics of the measured data. These adjustments are then applied to future GCM data. In this study, the method provided by Alcamo and Doll (2000) is used based on the following relationships:

Equation (4) $$T'_{GCM,Fut} = (\overline{T}_{Obs} - \overline{T}_{GCM,His}) + T_{GCM,Fut}$$

Equation (5) $$P'_{GCM,Fut} = (\overline{P}_{Obs} / \overline{P}_{GCM,His}) \times P_{GCM,Fut}$$

In the above relationship:

$\overline{T}_{Obs}$ and $\overline{P}_{Obs}$, respectively, are the average temperature measured at the desired stations

$\overline{T}_{GCM,His}$ and $\overline{P}_{GCM,His}$ are the average temperature of the previous data of the general circulation model (common period with observations)

$T_{GCM,Fut}$ and $P_{GCM,Fut}$ are the initial data of the general circulation model for future periods

$T'_{GCM,Fut}$ and $P'_{GCM,Fut}$ are future data after correction (Alcamo et al., 2000).

Evaluation of the average minimum temperature in the upstream parts of the Zayandehrud watershed based on scenario RCP4.5 indicates that the minimum temperature will increase by 2040. The intensity of the incremental changes will be 2.6 °C during December, 1.7 °C during January, and 2.2 °C during February. The increase in minimum temperature at Fereydunshahr station is more intense than Daran. This increase in temperature will have a significant effect on snowfall and its continuity during these seasons (Figures 2-12 and 2-13).

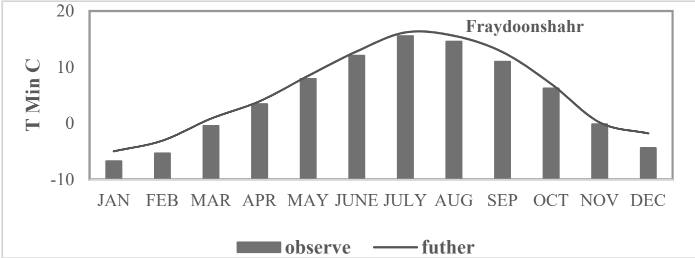

Figure 2-12 Comparison of long-term minimum temperature changes of the past and future periods based on CORDEX data output

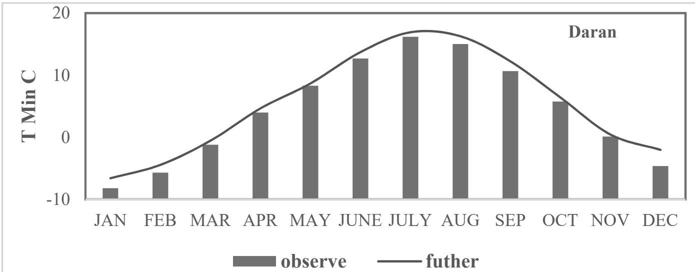

Figure 2-13 Comparison of long-term minimum temperature changes of the past and future periods based on CORDEX website output

Monthly changes based on scenario RCP4.5 during the 12 months of the year led to an increase in maximum temperature so that according to the scenario, the threshold for changes will be between 0.2 and 2.2. C at study stations. The highest increase in maximum temperature will be during the colder months of the year, especially December and January (Figures 2-14 and 2-15).

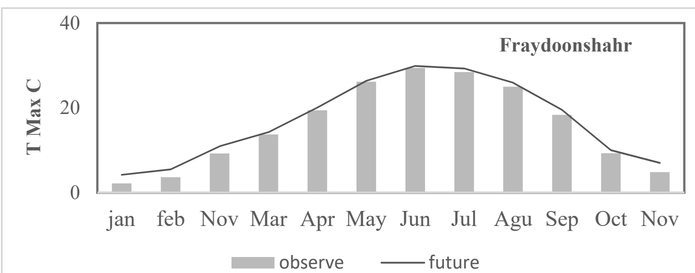

Figure 2-14 Comparison of long-term maximum temperature changes of the past and future periods based on CORDEX website output

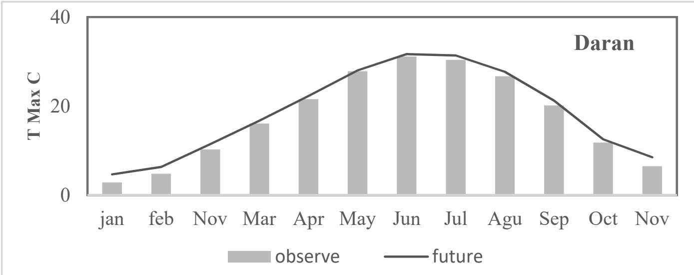

Figure 2-15 Comparison of long-term maximum temperature changes of the past and future periods based on CORDEX website output

4. Conclusion

Eventually, the changes in major climatic parameters, especially rising temperatures, affect the hydrological cycle of the Zayandehrud watershed during the future climatic period. Changes in the hydrological cycle for the period of 2011-2040, proportional to the increase in temperature, will result in changes to the pattern of precipitation and the continuation of drought and extreme events. What is expected is that with the increase in temperature in the coming period, orographic precipitation in mountainous (upstream) areas will trend toward rainy conditions rather than snowy-rainy conditions in the previous period. In this case, the accumulation of snow and its gradual summer melting and deep soil penetration that supports river baseflow will be disrupted. Finally, a study of precipitation changes revealed that with the increase in temperature that increases evaporation, there is no doubt that in the coming years, there will be a possibility of continued and severe drought in the upstream parts of Zayandehrud. Therefore, with this amount of changes, various areas of the watershed will face a deficit of water resources, and returns to average precipitation conditions will decrease.

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