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Planning in Germany and Iran
Responding to Challenges of Climate Change through Intercultural Dialogue

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

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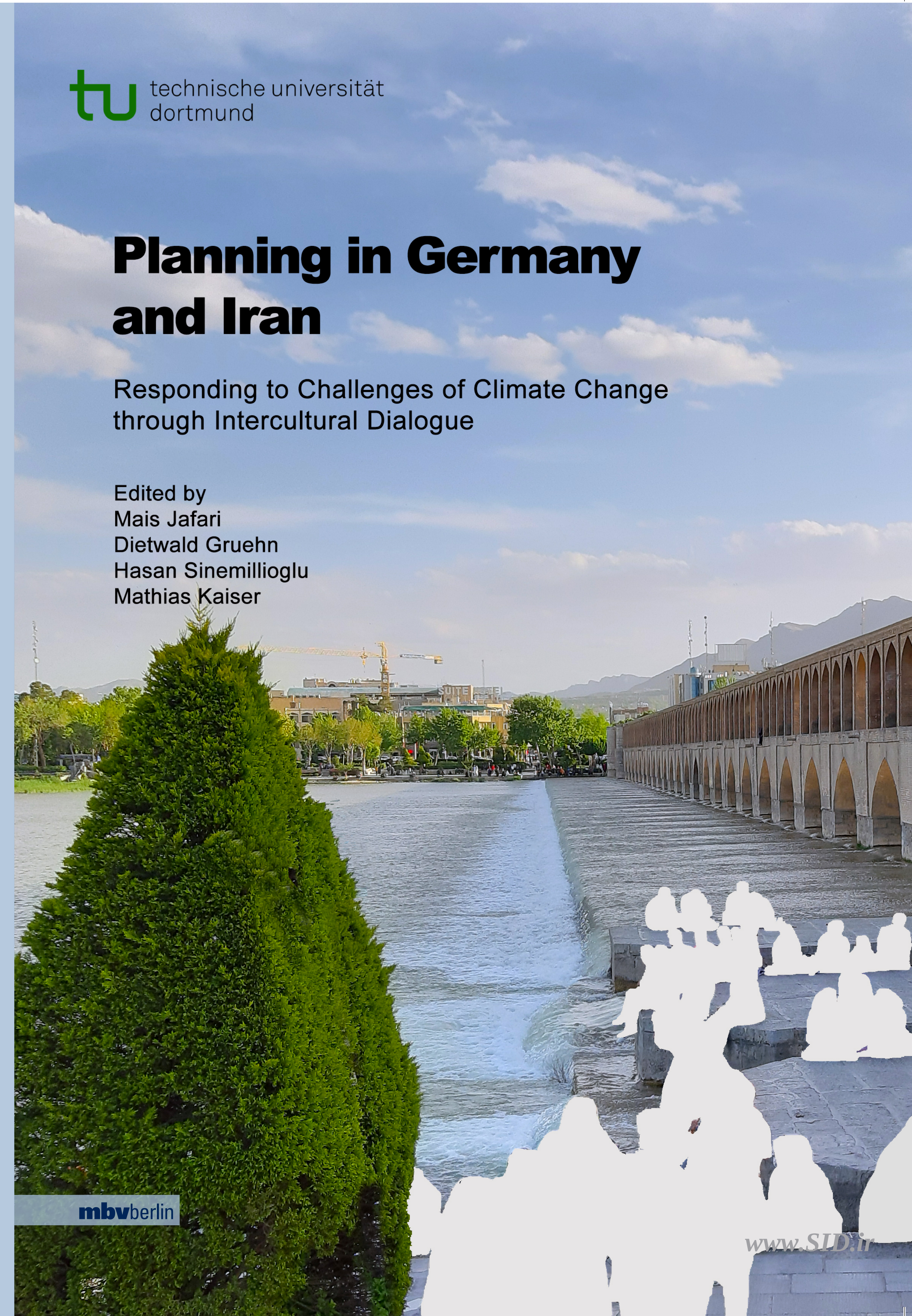

technische universität dortmund

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عنوان :

طبقه‌بندی مقایسه ای اقلیم ایستگاه‌های حوضه آبخیز زاینده رود با روش کوپن-گایگر

Comparative Climate Classification in Zayandehrud Watershed Stations with Köppen-Geiger Method

گروه تخصصی: فنی مهندسی

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1.

Comparative Climate Classification in Zayandehrud Watershed Stations with Köppen-Geiger Method

Maryam Ahmady, Amir Masoud Samani Majd, Bryce Timothy Lawrence

Abstract

Climate classification is one of the prerequisites for regional and ecological planning and can be used to discover the natural potential for ecological sustainability and guide land use planning. Especially in arid regions, such as central Iran, management of water resources in the face of projected increased aridity due to climate change is a key goal of regional planning. The aim of this study is to compare the TYN SC 2.03 global climate change models for SRES scenario A1F1 2001-2025 in the Zayandehrud River basin (Esfahan, Iran) with historical meteorological data collected locally from 1951-2014, to create a comparative baseline that frames climate projections in the basin through the end of the 21st century. Climate classification in the TYN SC 2.03 dataset was calculated using the Köppen-Geiger method and thus, this method is used to calculate climate classes from the local data. Local data includes daily weather data from 11 synoptic weather stations in the Zayandehrud basin, with the observation period ranging between six and 63 years depending on the station. The results showed that five out of 11 local stations matched the climate classification as predicted by TYN SC 2.03, including stations located in desert (BWh, BWk) and snowy climates (Dsa). The remaining six stations were classified as desert (BWh, BWk) with local data, whereas the TYN SC 2.03 dataset predicted steppe (BSk). The results verify that local meteorological datasets are either comparable to the TYN SC 2.03 global climate model or predict one climate classification warmer and dryer.

Keywords: Zayandehrud watershed, Köppen-Geiger, Climate classification

1. Introduction

Recognition of natural potentials as the basis of human activities forms the basis of most environmental and land use planning. However, the implementation of sustainable development in different regions requires careful planning based on resource potentials and constraints. The climate of each region is one of the most important factors determining its development potential (Davoodi et al., 2013:22; Lawrence, 2019:43).

There are several methods of climate classification, each with its own advantages and limitations. The most popular climate classification methods are Köppen-Geiger (1936), De Martonne (1923), Thornthwaite (1931). The Köppen-Geiger climate classification is one of the most important and reputable methods of climate classification, which has been in use for more than 80 years. Köppen (1900, 1931, 1936) classified the Earth based on the amount of temperature and precipitation as well as seasonal changes to the five main climatic groups, including equatorial climates (A), arid climates (B), warm temperate climates (C), snow climates (D) and polar climates (E). Climate groups are then divided into sub-groups based on temperature and precipitation, then into sub-divisions based on the seasonal distribution of temperature and precipitation. Various researchers have criticized the original Köppen method (1900), especially on how the boundaries of the climatic regions used in this method were determined (Köppen and Geiger 1930:6; Trewartha 1980:76; Rudloff 1981:34; Guetter and Kutzbach 1990:16). Researchers were able to correct some of the shortcomings related to boundary definition of the Köppen method, and subsequently published the modified Köppen-Geiger method in 1936 (Köppen-Geiger 1936; Raziei, 2017:182).

Köppen and Geiger (1930) compiled the first Köppen-Geiger climate classification map manually. It has been used in many studies and research, including Kleidon et al. (2000). In this study, the effect of vegetation changes in the global climate was studied and evaluated using the Köppen-Geiger climate classification method and simulation of climatic models. Rubel and Kottek (2006) updated the global climate map using the Köppen-Geiger method, using networked data and monthly global precipitation with an accuracy of 0.5 geographical degrees for the period of 1951-2000 (Figure 1-1).

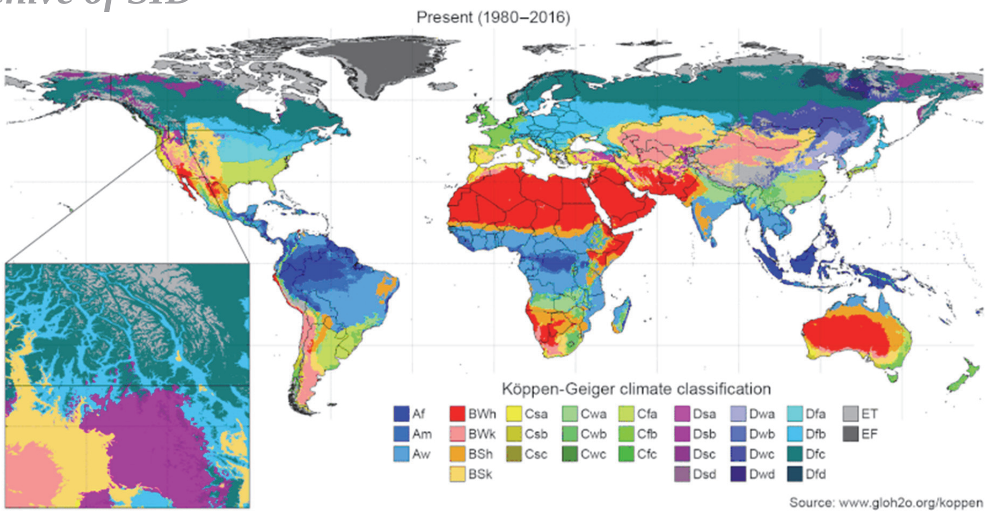

Figure 1-1 Climate map of the world using the Köppen-Geiger method (Source: www.gloh2o.org/koppen)

Peel et al. (2007) also used long-term historical global precipitation and temperature data to provide another map of the world's climate classification using the Köppen-Geiger method. Rubel and Kottek (2010) also used grid data of monthly temperature from the Climatic Research Unit (CRU) and monthly precipitation from the Global Precipitation Climatology Centre (GPCC) data to provide another map of the Köppen-Geiger climate classification for the Earth and examined the displacement of climatic regions as a result of climate change. Raziei (2017) classified the climatic regions of Iran using the Köppen-Geiger method. Mirzaei et al. (2019) was used IPCC Scenarios and Köppen-Geiger Climate classification for prediction of Climate Change in the Zayandehrud watershed and suggested some adaptation strategies for climate change management. In this study, monthly temperature data and average monthly rainfall (1951-2000) were used to calculate Köppen-Geiger climate (Nakicenovic et al. 2000). Based on the results of this study, the area of temperate climate (Csb, Dsa, Dsb) in the west of the country will drastically decline by 2100, being replaced by desert climates (Bsh, Bsk, BWh) in all areas of Iran except for a small area in the Zagros Mountains at 35° N x 47.5° E (Figure 1-2). Given the traditional distribution of agricultural lands in the upland temperate climates of Iran, this change could significantly reduce the arable land and thereby agricultural production in Iran.

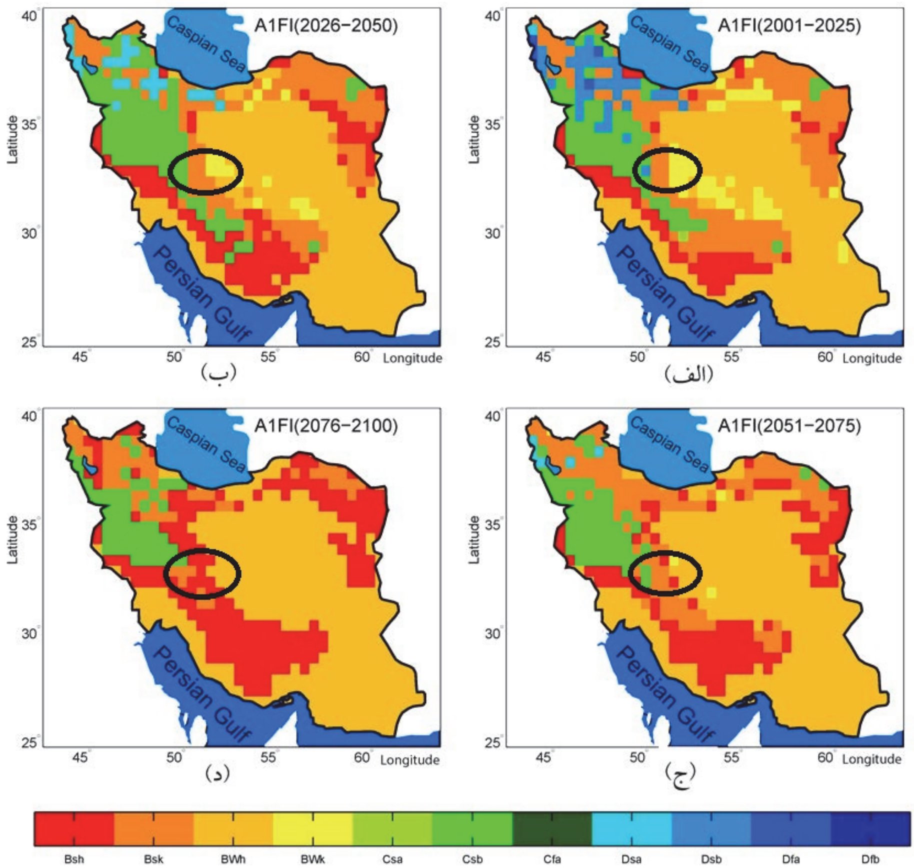

Figure 1-2 Köppen-Geiger Climate Projections for the A1F1 scenario through the end of the 21st century. Zayandehrud Basin is shown approximately with a black oval on the figure (Figure reproduced from Raziei, 2017)

2. Materials and methods

2.1 Study Area:

2.2 Zayandehrud watershed

Zayandehrud watershed, with an area of 4135,000 hectares, is located in the center of Iran. Its main river is Zayandehrud, which originates from the slopes of the Middle Zagros (Koohrang) in Chaharmahal and Bakhtiari Province and flows east to west, eventually emptying into the Gavkhuni swamp. This basin consists of 7 sub-basins named Plasjan, Shoor-Dehaghan, Khoshkrud, Morghab, Zarcheshmeh, Rahimi and Gavkhuni swamp. Each sub-basin is divided into a number of hydrological units, for a total of 20 units. About 93% of this basin is located in Esfahan and about 7% in Chaharmahal Bakhtiari province. In general, the study area is geographically located on the transportation routes of the southern and central provinces of the country and includes the cities of Esfahan, Daran, Fereydunshahr, Najafabad, Zarrinshahr, Khomeini Shahr, Shahreza and Mobarakeh, and it is of particular importance. Figure 1-3 shows the Zayandehrud watershed.

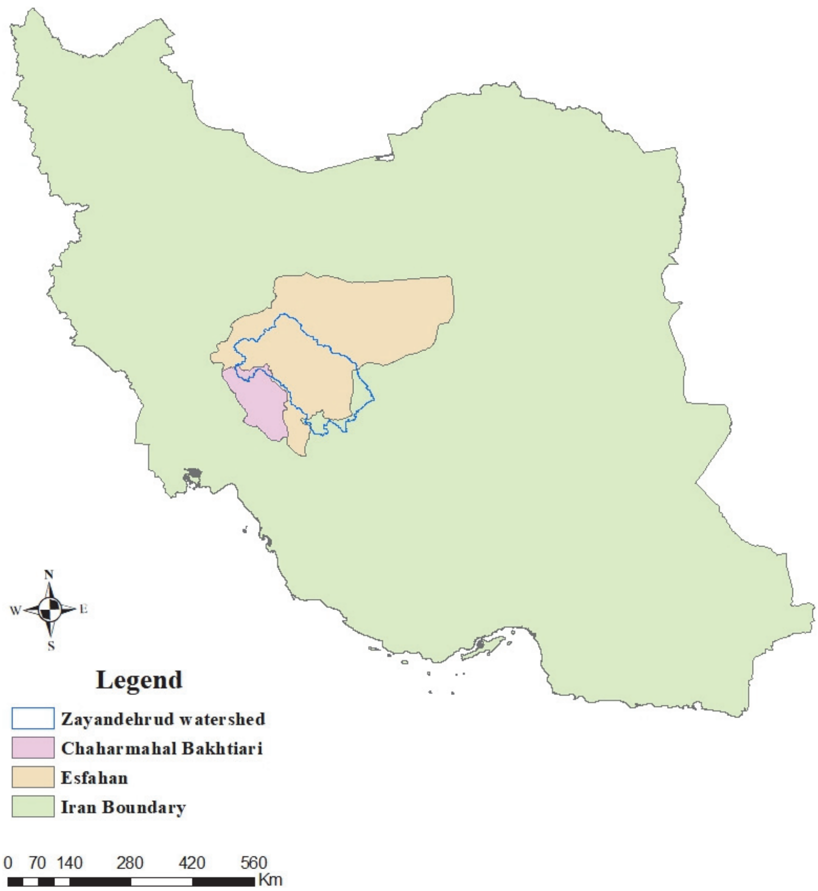

Figure 1-3 Location of Zayandehrud watershed (Source: Authors own work, 2020)

2.3 Meteorological data

In this study, daily statistics of meteorological parameters of synoptic stations in Zayandehrud watershed were used. The statistical years of each station are different and depend on the year of their establishment, and in general, daily we used statistics from the establishment of the station until 2014. Table 1-1 shows the names of the used stations along with the used statistical period.

Figure 1-4 shows the synoptic stations of the Zayandehrud watershed. There are 24 synoptic stations in Esfahan province, 14 of which are in Zayandehrud watershed. The meteorological information obtained was initially examined and the stations with incomplete meteorological information were removed, and finally, 11 stations were examined for this study with datasets ranging from six to 63 years (Table 1-1).

Table 1-1 Properties of stations used for climatic classification

Elevation	latitude	longitude	period	Station
1713.8	3584775	535554	2005-2014	Zarrinshahr
1450	3585924	652045	2006-2015	Varzaneh
1858	3538690	576578	1994-2014	Shahreza
1673	3660629	545109	2002-2014	Murchehkhort
1550	3597930	566272	1951-2014	Esfahan
1980	3699340	515493	1999-2014	Meymeh
1636	3607503	536412	2003-2014	Najafabad
2490	3644973	418412	2004-2014	Fereidunshahr
1680	3580306	542469	2009-2014	Mobarakeh
2290	3647770	440814	1992-2014	Daran
1542	3598013	578269	1987-2014	Kabutarabad

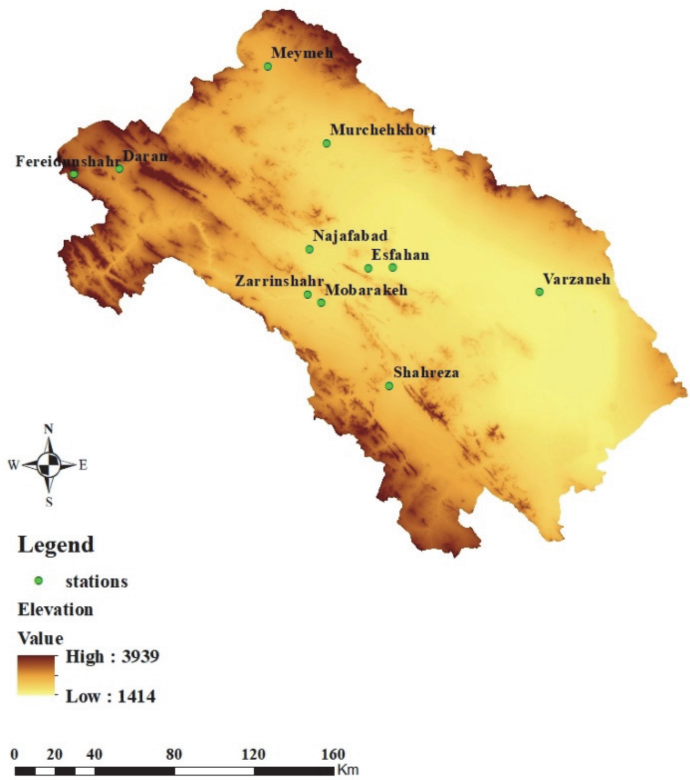

Figure 1-4 Synoptic stations of Zayandehrud watershed (Source: Authors own work, 2020)

2.4 Köppen-Geiger climate classification method

The first two letters of the five main climatic regions, including Tropical (A), Dry (B), Temperate (C), Continental (D), and Polar (E), are defined with temperature and precipitation parameters as described in Table 1-2. The third letter in the Köppen system is defined with the temperature parameters as described in Table 1-3. The formula described in equation 1 was calculated for each station based on the reported temperature and precipitation data.

Table 1-2 Criteria for determining the main Köppen-Geiger climate groups (Kottzek et al., 2006: 260)

Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18\ ^{\circ}C$
Af	Equatorial rainforest, fully humid	$P_{min} \geq 60$ mm
Am	Equatorial monsoon	$P_{ann} \geq 25(100 - P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60$ mm in summer
Aw	Equatorial savannah with dry winter	$P_{min} < 60$ mm in winter
B	**Arid climates**	$P_{ann} < 10\,P_{th}$
BS	Steppe climate	$P_{ann} > 5\,P_{th}$
BW	Desert climate	$P_{ann} \leq 5\,P_{th}$
C	**Warm temperate climates**	$-3\ ^{\circ}C < T_{min} < +18\ ^{\circ}C$
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Cw	Warm temperate climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Cf	Warm temperate climate, fully humid	neither Cs nor Cw
D	**Snow climates**	$T_{min} \leq -3\ ^{\circ}C$
Ds	Snow climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Dw	Snow climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Df	Snow climate, fully humid	neither Ds nor Dw
E	**Polar climates**	$T_{max} < +10\ ^{\circ}C$
ET	Tundra climate	$0\ ^{\circ}C \leq T_{max} < +10\ ^{\circ}C$
EF	Frost climate	$T_{max} < 0\ ^{\circ}C$

Table 1-3 Criteria for selecting the third letter of the Köppen-Geiger climate groups (Kottek et al., 2006: 262)

Type	Description	Criterion
h	Hot steppe / desert	$T_{ann} \geq +18\ ^{\circ}C$
k	Cold steppe /desert	$T_{ann} < +18\ ^{\circ}C$
a	Hot summer	$T_{max} \geq +22\ ^{\circ}C$
b	Warm summer	not (a) and at least 4 $T_{mon} \geq +10\ ^{\circ}C$
c	Cool summer and cold winter	not (b) and $T_{min} > -38\ ^{\circ}C$
d	extremely continental	like (c) but $T_{min} \leq -38\ ^{\circ}C$

Equation 1

For P_{th}

Where:

T_{ann} is the average annual temperature,

T_{max} and T_{min} are the average temperatures of the hottest and coldest months of the year,

P_{ann} is the highest total annual precipitation,

P_{smax} and P_{smin} are the highest and lowest summer rainfall, respectively, and

P_{wmax}, P_{wmin} are the highest and lowest winter precipitation.

The final step is to compare the present classification with the predicted values. Fossil fuels have been the most important source of energy in Iran, and given that the SRES A1F1 scenario (Nakicenovic, 2000) emphasizes the continued use of fossil fuels, the results were compared with the results of the prediction of this scenario in the study of Rubel and Kottek (2010:19).

3. Results

Figure 1-5 shows the long-term average temperatures at the 11 local stations plotted in a bar chart. The average temperature ranges from 11 to 18.9 °C. The lowest average temperature is for Daran station with 11 °C, followed closely by Fereidunshahr station with an average temperature of 11.5 °C. The highest average temperatures of 18.9 and 18.7 were found at Varzaneh and Najafabad stations.

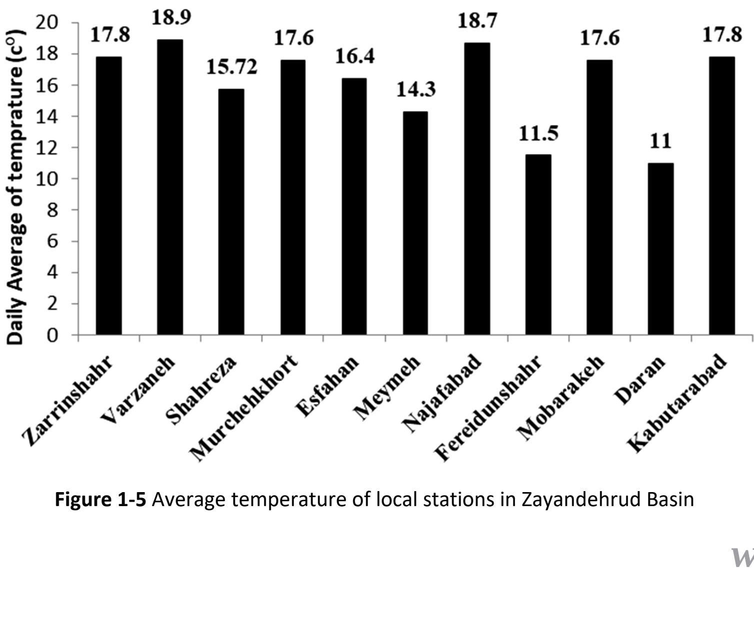

Figure 1-5 Average temperature of local stations in Zayandehrud Basin

Figure 1-6 shows the average annual precipitation at the 11 local stations plotted in a bar chart. The average precipitation ranges from 107.8mm to 599mm. The highest annual precipitation of 599 mm was found at Fereidunshahr station and the second most precipitation of 350mm was found at Daran station. Both Fereidunshahr and Daran stations are located in the northwestern part of the basin in a mountainous area at over 2000m elevation, indicating orographic origin of precipitation. The least precipitation was found at Kabutarabad and Varzaneh stations, with an average precipitation of 107.8 and 109.6 mm, respectively. Kabutarabad and Varzaneh stations are located at the lowest elevation of all 11 stations.

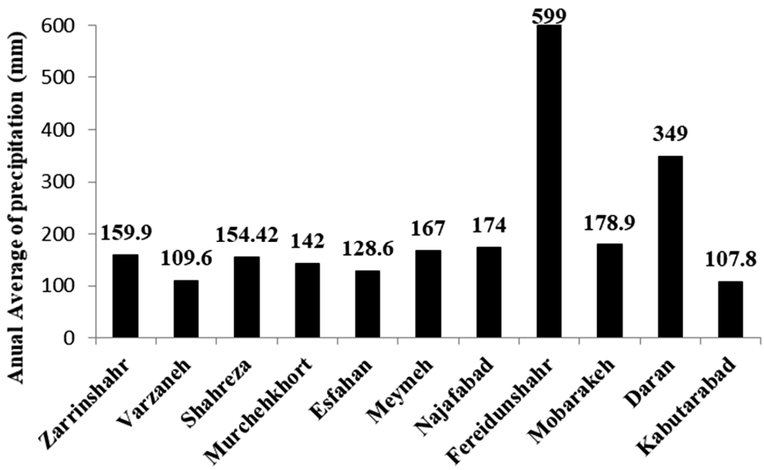

Figure 1-6 Average precipitation in Zayandehrud watershed stations

The comparison of climate classification of local stations using the Köppen-Geiger method as described above in equation (1) and the climate classes predicted by the global TYN SC 2.03 A1FA dataset (Rubel and Kottek 2010:19) is presented below in Table 1-4. The comparison includes the Köppen-Geiger climate classification of the local stations and the station observation length, the predicted Köppen-Geiger classification from TYN SC 2.03, and a comparison of climate class calculated by the global versus local method.

Table 1-4 Köppen-Geiger Climatic classification comparison between TYN SC 2.03 and local weather station data (Authors own data and data from Rubel and Kottek, 2010: 19)

Station	Observation Length (yrs)	Köppen-Geiger Classification from TYN SC 2.03 A1F1 SRES Scenario	Köppen-Geiger Classification from Local Weather Station Data	Comparison
Mobarakeh	6	BSk	BWh	Dryer than TYN SC 2.03 predicted
Varzaneh	8	BWh	BWh	Same as TYN SC 2.03
Zarrinshahr	9	BSk	BWk	Dryer than TYN SC 2.03 predicted
Fereidunshahr	10	Dsa	Dsa	Same as TYN SC 2.03
Najafabad	11	BSk	BWh	Dryer than TYN SC 2.03 predicted
Murchehkhort	12	BSk	BWk	Dryer than TYN SC 2.03 predicted
Meymeh	15	BSk	BWk	Dryer than TYN SC 2.03 predicted
Shahreza	20	BSk	BWk	Dryer than TYN SC 2.03 predicted
Daran	22	Dsa	Dsa	Same as TYN SC 2.03
Kabutarabad	27	BWk	BWk	Same as TYN SC 2.03
Esfahan	63	BWk	BWk	Same as TYN SC 2.03

*TYN SC 2.03 based climate classification from Rubel and Kottek (2010)

According to both local and global datasets, all stations under 2000m elevation in the Zayandehrud basin are in the dry climate group (B), and the two stations over 2000m elevation are both in the snowy-forest climate with hot and dry summer (Dsa) climate sub-division. The two stations classified as Dsa are both located in the snowmelt fed headwaters of the Zayandehrud River basin. Differences in desert sub-groups and sub-divisions were found in both local and global datasets. The TYN SC2.03 dataset predicted cold steppe sub-division (BSk) in Mobarakeh, Zarrinshahr, Najafabad, Murchehkhort, Mezmeh, and Shahreza stations, hot desert (BWh) at Varzaneh station, and cold desert (BWk) Esfahan and Kabutarabad stations. In contrast, the local meteorological station data predicted that all stations under 2000m are in the desert sub-group (BW) with hot desert sub-divisions (BWh) in Mobarakeh, and Varzaneh, and cold desert sub-divisions (BWk) in Zarrinshahr, Murchehkhort, Meymeh, Shahreza, Kabutarabad and Esfahan stations. The prediction of the Köppen-Geiger climate classes from SRES A1F1 scenario (Rubel and Kottek 2010:19) those from local data were identical in Varzaneh, Esfahan, Daran, Fereidunshahr and Kabutarabad stations. The primary differences were in the distinction between steppe and desert (Pann > or < 5 Pth) and hot or cold desert (Tann > or < 18°C).

4. Discussion

The results of climate classification from local meteorological data compared well to the global (Rubel and Kottek 2010) climate classification calculated from the TYN SC 2.03 dataset at the climate group level, indicating scalability of the Köppen-Geiger climate classification method.

The major difference between the global and local outcomes was the classification of sub-groups and sub-divisions with the desert climate, where classification from local data indicated either a dryer or hotter sub-climate than global data or both. The shorter length of local data as compared to the longer-term global datasets could explain this finding. All local stations that predicted desert climates when TYN SC 2.03 predicted steppe climate have records ranging from six to 20 years, whereas stations with 22-63 years of data predicted the same climate type as TYN SC 2.03. Long term data is typically required to predict climate changes, with a 30-year minimum typical for climate change studies (WMO, 2017). Thus, the prediction of desert rather than steppe in areas under 2000m could also indicate recent drought rather than climate change. Conversely, it may indicate that more recent temperature and rainfall records show warmer and dryer conditions than longer datasets that are offset by the generally cooler and wetter conditions of the late 20th century (Delworth and Knutson 2000).

A warming and drying trend in the past 20 years could also be logical given that the world has generally kept within the A1F1 scenario, able only to reach legally binding consensus amongst industrialized nations accounting for about half of C02 emissions according to the Paris Agreement chapter XXVII section 7.d. In addition, the accelerated trend of fracking and oil-shale extraction in North America (Kilian 2017) has glutted the global oil market, while the promising but slow movement towards electric mobility (Thiel et al. 2020:1) means continued automobile-based C02 emission for the foreseeable future. Indeed, Europe’s largest industrialized economy, Germany, has only recently agreed to phase out lignite coal-fired power plants by 2038 (BBC 2020), a full generation from now. Given that the global SRES scenarios calculated by Rubel and Kottek are 10-years old at this point, the emerging dryer and warmer trend in the past six to 20 years indicated in the shorter-term local data could simply be indicative of a warming and drying trend in this semi-arid region.

Although compared only generally in this study, the results from the local dataset also appear to be consistent with the national level calculated Köppen-Geiger climate sub-divisions from Raziei (2017), where the single pixel of Dsa is visible on Figure 1-2 A1F1 scenario at higher elevations and the BS and BW climates are predicted at lower elevations. Thus, local data from Zayandehrud basin appear to confirm the SRES A1F1 modeling results for 2001 to 2025 from Raziei (2017). The similarity of A1F1 from this study and Raziei (2017) indicate that the projections for the central Iranian plateau and Zagreb Mountain region are plausible. Further, based on the warmer and dryer predictions from local data compared to global data in Rubel and Kottek (2010), it is not impossible to believe that future trends of Dsa to Csb or even BSk displacement in the highlands could in fact happen more rapidly or be more widespread than the modeling indicates. Specifically, the retraction of the Dsa climate from snowy (D) to warm (C) or even dry (B) as predicted by both Rubel and Kottek (2010) and Raziei (2017) is especially troubling. In this case, the Fereidunshahr and Daran stations would appear closer to the other BW stations, losing up to 2/3 annual precipitation (599mm to 200mm) or almost half of precipitation (350mm to 200mm), respectively and increase by as much as 5°C at both stations. Reduction or loss of snow in the winter months in the Zagros Mountains will directly affect summer snowmelt that feeds the Zayandehrud River, potentially reducing summer baseflow in the Zayandehrud River and exacerbating summer water scarcity in Esfahan, a city of 2 million people.

The local data predictions of BW climate sub-group under 2000m rather than variant predictions of BS and BW in the global dataset indicate that a change in land management strategies may be necessary, considering that steppe climates with 250mm rainfall per year are considered the minimum rainfall for arable farming in Iran (Mesgaran et al. 2017:7). If central plateau areas do indeed become desert rather than steppe, then groundwater supplies will likely need to be increased to cope with increases in temperature and evapotranspiration. Decentralized rainwater retention and storage may become an important land management strategy in this case to secure summer water supply.

5. Conclusion

Given the threat of climate change globally and especially in semi-arid regions that experience seasonal water scarcity, this study aimed to narrow the single semi-arid region of Zayandehrud River basin, Iran, to determine how well locally collected meteorological data reflects global climate prediction models. We found that local precipitation and temperature data from synoptic weather stations can be used to calculate the Köppen-climate classification and compared to global models with accuracy at the climate group level. In the Zazandehrud River basin, local data predicts warmer and dryer climate sub-group and sub-division distribution than the global models. Our findings indicate that future projections of SRES A1F1 climate change through 2100 from global models are credible when extrapolated down to the regional level and possibly conservative in the case of semi-arid regions. However, continued collection of systematic synoptic meteorological data, and periodic review of new data, is necessary to determine climate change trends in central Iran. The findings have implications for water and land management in the Zayandehrud River basin, namely that future generations may need to rely less on snow melt runoff in the summer months and rather will need to rely on larger scale up-stream reservoirs at higher elevations and decentralized rainwater management at lower elevations to adapt to predicted future water scarcity.

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