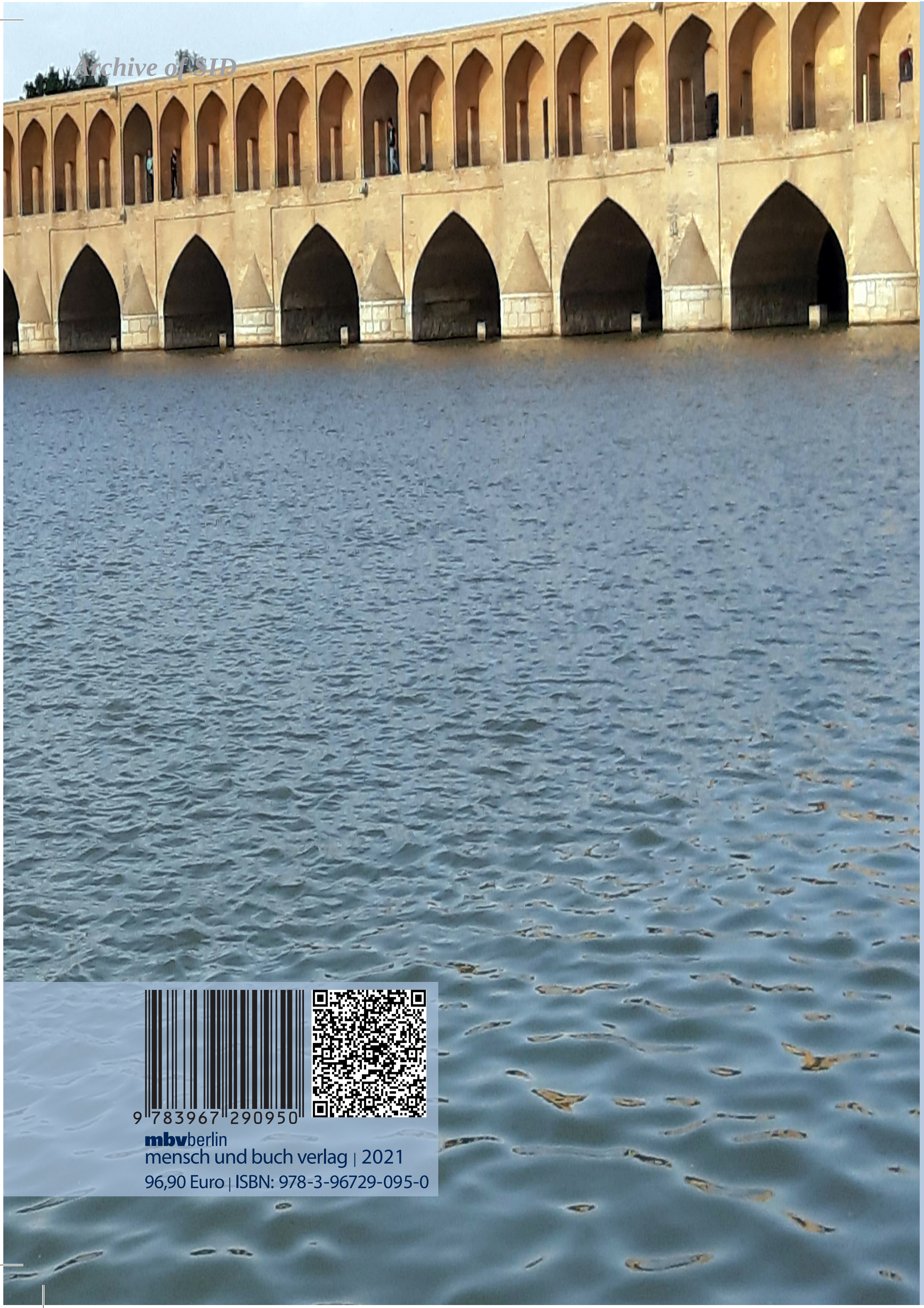

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Responding to Challenges of Climate Change through Intercultural Dialogue

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

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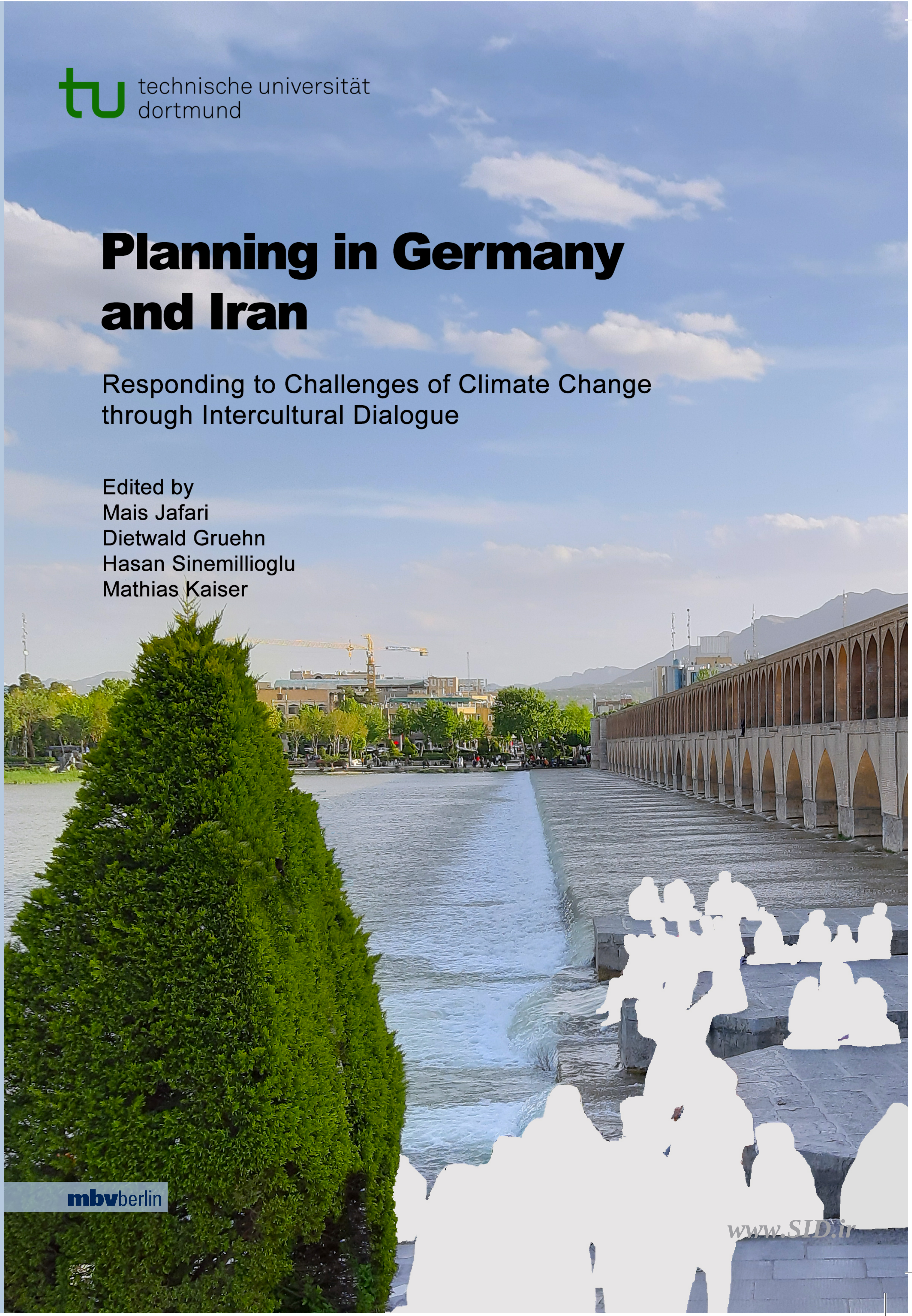

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عنوان :

بررسی طبقه بندی اقلیمی کوپن-گایگر حوزه آبخیز زاینده رود بر اساس سناریوهای IPCC

Investigation on Zayandehrud Watershed Köppen-Geiger Climate Classification based on IPCC scenarios

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4.

Investigation on Zayandehrud Watershed Köppen-Geiger Climate Classification based on IPCC scenarios

Mojgan Mirzaei, Amir Masoud Samani Majd, Bryce Timothy Lawrence

Abstract

Climate is a general condition of the prevailing weather conditions of a given location based on long-term statistics. The climatic conditions of every location play an important role in the dispersal of humans, animals and plants, so any activity or planning in the various economic, agricultural and industrial contexts at the ground is not possible without knowledge of the climate. For this reason, climatic division or recognition of climatic zones is essential in land use planning. Climate changes expected over the next 100 years are predicted to impact semi-arid climates especially hard by reducing annual rainfall in climates that are already water-stressed. The purpose of the present study is to predict climate change in the semi-arid Zayandehrud watershed, Iran, based on IPCC scenarios and Köppen-Geiger climate classification. In this study, the simulated monthly total precipitation from the Global Precipitation Climatology Centre (GPCC) and mean monthly temperature from the Climatic Research Unit (CRU) data were used to calculate Köppen-Geiger climate maps within the Zayandehrud watershed on a 0.5-degree grid (45 x 55 km) for three quarter-century periods from 2001 to 2100. Köppen-Geiger distribution in the quarter-century time series was calculated for four different socio-economic climate change mitigation scenarios ranging from fossil fuel-intensive economies (A1F1) to increasingly sustainable economies with application of technology (A2, B1, B2). The results of the scenarios indicate that Zayandehrud watershed will experience warming and desertification, with effects more evident at the upstream and downstream of the watershed. In all scenarios and time frames, the snow-capped mountainous headwaters of the Zayandehrud watershed will experience the most warming changes, leading to changes in the long-relied upon meltwater regime feeding the Zayandehrud River. Considering the anticipated conditions, climate mitigation and adaptation measures, including reducing greenhouse gas emissions, upgrading and deploying clean technologies and protecting forests against climate change, are essential.

Keywords: Climate change, Köppen-Geiger climate classification, Zayandehrud watershed, IPCC

1. Introduction

Climate is the general situation of the prevailing weather conditions of a specific location based on long-term statistics, typically 30-years or more (WMO 2017; Montazeri & Bai 2012). The combination of climatic elements in any given location, such as temperature, precipitation, pressure systems, prevailing winds, elevation, latitude and longitude, cause the formation of diverse and different climates on the Earth. These factors can also be used to predict where climate zones may migrate given changes in climatic elements (Hedayati Dezfooli & Kakavand 2012). Understanding the natural features of a region, especially the climate, can play a major role in land planning and preparation (Tavoosi & Delara 2010). Climate change is a naturally occurring phenomenon on Earth and typically results in fluctuations in rainfall and temperature that can disrupt natural ecosystems and change the balance between humans and the environment (Fanaei et al., 2017). Current research indicates that human-induced climate changes due to C02 emissions after industrialization are increasing the rate of climate change (IPCC 2014). Arguably the most important effect of this phenomenon is the impact on water resources of each region and its change over time (Kondori et al., 2019). With global warming and climate change occurring in the last decades of the twentieth century and continuing into the twenty-first century, the world is facing a new challenge that will have significant impacts on natural resources and the environment. These adverse effects include increased rainfall intensity and severe flooding, prolonged droughts, reduced snow resources at high elevations, sea-level rise increases in evaporation rates from natural lakes and freshwater reservoirs. These effects will likely exacerbate water shortages (IPCC 2014).

Although all the causes of climate change in the world are not fully understood, the debate over climate change has certainly been and will be of interest to many researchers. Human concerns about future climate change in recent years have attracted more attention to this issue (Saboohi et al., 2019). Since climate change is one of the main human concerns for future periods, it is necessary to consider climate change forecasting to improve management of this change (Foulad et al., 2011). The anticipation of the severity and geographic distribution of future climate changes likely to result from human activities and assessing the possible severity of such effects on the global environment in the coming decades are among the main research topics in the field of climate change (De Castro et al., 2007). The occurrence of the climate change phenomenon is not easily proven and requires comprehensive and long-term research. Yet, the process of global warming and the link to human-induced increases of carbon dioxide levels in the atmosphere is almost certain (Rashidi & Gharib 2011). Climatologists' efforts for prediction or numerical calculation and estimation of climatic elements have led to an important topic in this science, referred to as climate modeling (Razi 2017). With the development of greenhouse gas emission scenarios by the Intergovernmental Panel on Climate Change (Nakicenovic et al., 2000; Stocker et al., 2013), general circulation models of the atmosphere have been implemented with different emission hypotheses A1F1, A2, B1, B2 (Table 4-1) to predict geographic, climatic redistribution in the coming decades (Babaeian et al., 2005).

Based on studies carried out by Montazeri and Karimpour (2011) using multivariate statistical methods, Zayandehrud watershed can be divided into 5 climatic zones: cold and rainy, semi-cold with low rainfall, moderate and relatively dry, semi-cold with very low rainfall, and moderate, dry and dusty (Figure 4-1).

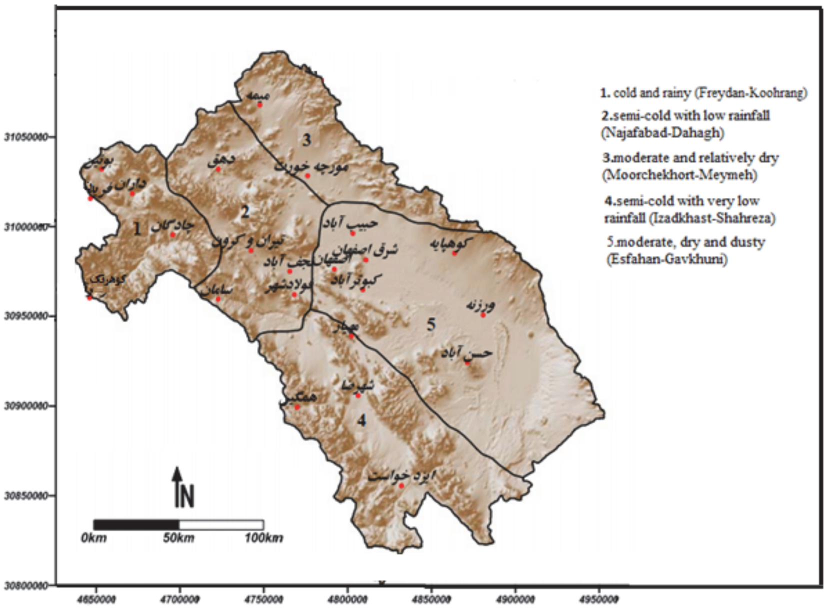

Figure 4-1 Climatic zoning of Zayandehrud watershed
(Adapted from Montazeri and Karimpour, 2011)

There have been many studies on climate change and climate forecasting. In Australia, tropical rivers are classified to predict the effects of climate change (Wayne Erskine et al., 2006). In addition, future changes in all Köppen-Geiger climate classifications have been studied (Crosbie et al., 2012). Taei Samirami et al. (2015) predicted changes in some climatic variables (precipitation, minimum temperature, maximum temperature and radiation) using the LARS-

WG exponential small-scale model under different scenarios and droughts of the 2010s- 2030s under the influence of climate change for Eskandari watershed, Esfahan province.

The aim of this study is to review the predicted the Köppen-Geiger climatic classification of Zayandehrud watershed using existing global-scale climate modeling for all four SRES scenarios between 2001 and 2100 to link global models to locations in the Zayandehrud Rwatershed where climate changes are predicted to occur.

2. Materials and methods

2.1 Study area

Zayandehrud watershed (Figure 4-2), with an area of about 41,500 square kilometers, is a completely closed watershed that has no access to the sea and is located in the center of the Iranian Plateau. The Zayandehrud River, with a length of about 350 km, generally flows west to east. The river originates from the Zagros Mountains and ends at Gavkhuni Wetland. This river provides the agricultural, urban and industrial water requirements of Esfahan, the third-largest city in Iran with approximately 2 million inhabitants.

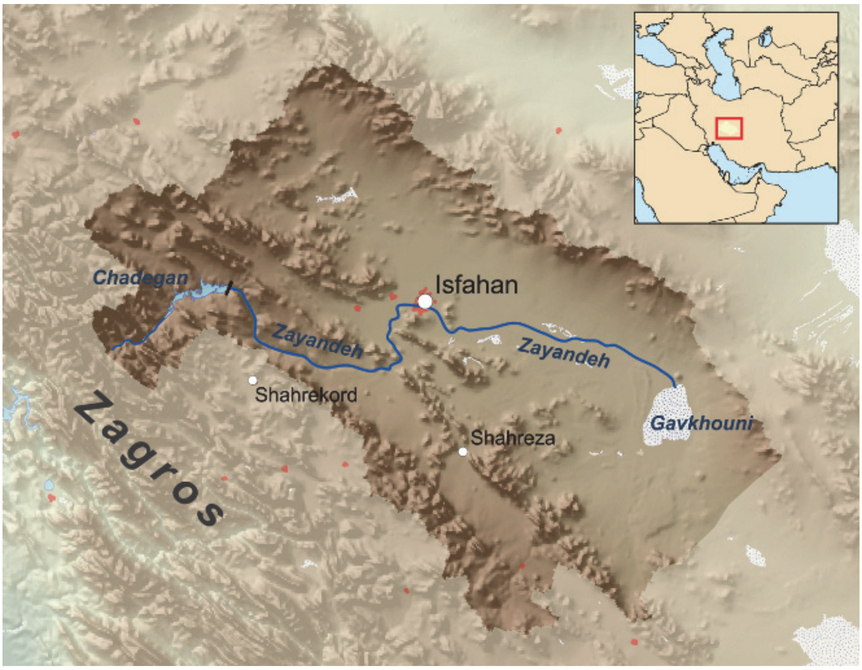

Figure 4-2 Location of the study area (Source: Authors own work, 2020)

2.2 Method

In this study, the simulated monthly temperature and precipitation data of TYN SC 2.03 for the period of 2001-2100 (Mitchell et al., 2004) are used. The simulated monthly temperature and precipitation data of TYN SC 2.03 are obtained from the average performance of five general circulation models (GCMs) of atmosphere for four different scenarios of greenhouse gas emissions (SRES scenarios) in the world in the 21st century. The special report on emissions scenarios (SRES) defines four different scenarios of the relationship between the factors influencing greenhouse gas emissions and their changes over time (Nakicenovic et al., 2000; Stocker et al., 2013; Arnell et al., 2004). Each of these scenarios predicts a different picture of the future for the world.

The A1 scenario shows a picture of the future in which the world economy is growing rapidly and modern technologies develop quickly as well. In contrast, the A2 scenario predicts a heterogeneous world for the future in which most people adhere to family values and local traditions. The B1 scenario predicts a world without materialism for the future and in which clean technologies replace polluting technologies. The B2 scenario predicts a world for the future in which the main focus is on finding local solutions to achieve economic development and ecological sustainability. In defining the mentioned scenarios, population growth, economic development, energy consumption, energy efficiency and a combination of energy consumption technologies have been considered, respectively. Within the TYN SC 2.03 dataset, scenario A1 is modeled as the A1F1 scenario, in which the global consumption of fossil fuels is predicted to continue on its current trajectory (Table 4-1). In this study, these four scenarios of A1F1, A2, B1, and B2 are used to evaluate climate change in the Zayandehrud watershed.

Table 4-1 Special report on emissions scenarios (SRES) description
(Adapted from Nakicenovic et al., 2000: 173-174)

Scenario	Scenarios Describing
A1F1	A fossil fuel-intensive world with quick economic growth and rapid application of new technologies
A2	A world with high diversity and focus on family values and local traditions
B1	A world without materialism and with launch of clean technologies
B2	A world with focus on local solutions for economic and ecological sustainability

There are several ways for climate classification, each with its own advantages and limitations. The most popular climatic classification methods are Köppen-Geiger, De Martonne, Amberge, Selyaninov, Thornthwaite, and others (Ahmadi et al., 2019). Since Köppen first introduced the climate classification method in 1900, changes have been proposed by various researchers to improve this method, resulting in several variations of this climate classification system (Mirzaei et al., 2019). This study summarizes the SRES scenario-based climate changes using spatial datasets prepared by Kottek et al. (2006) and Rubel and Kottek (2010), where the Köppen-Geiger classification method was used to classify global climatic zones under all four SRES scenarios. According to this classification, the Earth is divided into five major divisions based on precipitation, temperature and seasonal changes, including A (tropical), B (dry), C (temperate), D (continental), and E (polar), then subdivided based on seasonal rainfall and temperature distribution (Table 4-2). The Köppen-Geiger climate classes present in Iran are listed in Table 4-3 below.

Table 4-2 The main groups of Köppen-Geiger climate division
(Adapted from Strahler and Strahler, 1996; Lawrence, 2019)

Köppen-Geiger System of Climate Classification		
First Letter	**Short Description**	**Details**
A	Tropical Climate	All monthly temperature over 64.4 degrees F
B	Dry Climate	Boundaries determined by formula using mean annual temperature and mean annual precipitation
C	Warm Climate	Mean temperature of the coldest month between 64.4 degrees F and 26.6 degrees F
D	Snow Climate	Warmest month mean over 50 degrees F; coldest month mean under 26.6 degrees F
E	Ice Climate	Warmest month mean under 50 degrees F
Second letter	**Description**	
S	Steppe climate	
W	Desert climate	
f	Sufficient precipitation in all months	
m	Rainforest despite a dry season (i.e., monsoon cycle)	
s	Dry season in summer of the respective hemisphere	
w	Dry season in winter of the respective hemisphere	
Third letter	**Description**	
a	Warmest month mean temperature over 71.6 degrees F	
b	Warmest month mean under 71.6 degrees F; at least 4 months have means over 50 degrees F	
c	Fewer than 4 months with means over 50 degrees F	
d	Fewer than 4 months with means over 50 degrees F; coldest mean month under 36.4 degrees F	
h	Dry and hot; mean annual temperature over 64.4 degrees F	
k	Dry and cold; mean annual temperature under 64.4 degrees F	

Table 4-3 Characteristics of Köppen climate groups in Iran

Number	Name of Köppen-Geiger climate	Attributes
1	BWh	Desert climate-hot steppe
2	BWk	Desert climate-cold steppe
3	BSh	Steppe climate
4	BSk	Cold semi-arid climate
5	Csa	Warm temperate climate with dry summer
6	Cfa	Warm temperate climate, fully humid
7	Dsa	Snow climate with dry and hot summer
8	Dsb	Snow climate with dry summer

In order to report climate changes, the Zayandehrud watershed boundary was overlaid onto an identical pixel network of 45 x 55 km as used by Rubbel and Kottek (2010), thereby dividing the watershed into 28 pixels (Figure 4-3). For each SRES scenario, the current period (2001-2025) is compared to 2026-2050, 2051-2075, and 2026-2100 (i.e., three comparisons per SRES scenario), resulting in 12 total climate change comparisons. In each of the 12 comparison scenarios, pixels predicted to experience a climate change are reports, along with the current and predicted Köppen-Geiger category.

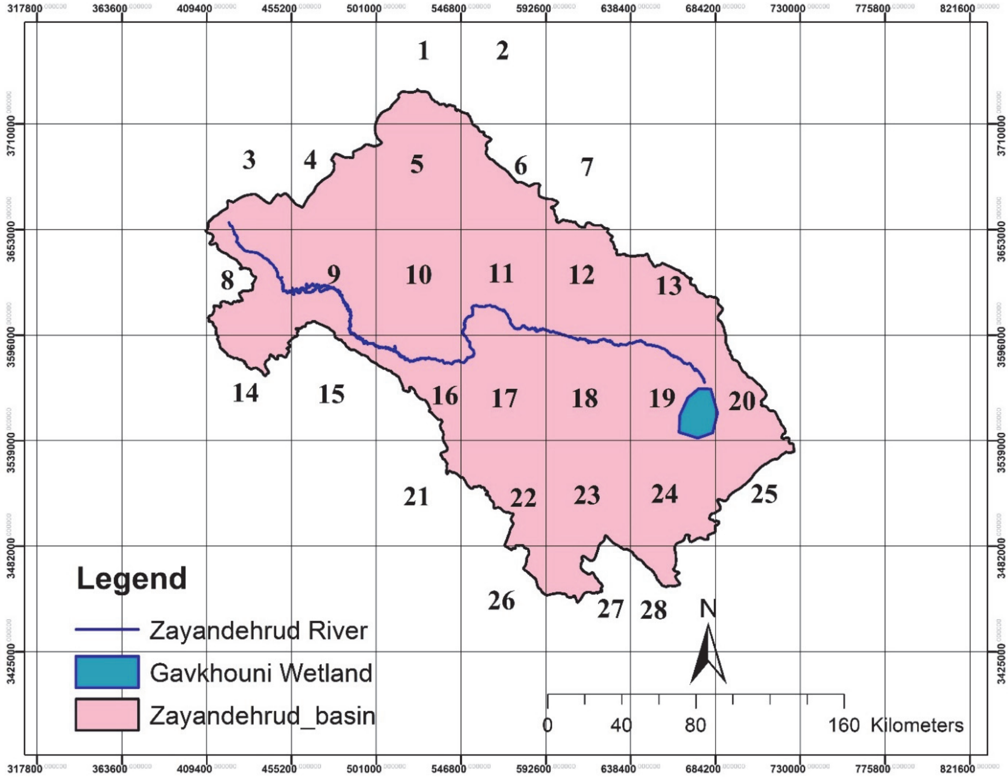

Figure 4-3 Grid of Zayandehrud watershed into 28 pixels with a size of 45 by 55 km Gavkhouni (Source: Authors own work, 2020)

3. Results

3.1 Climate zones in the 21st century

The projected Köppen-Geiger climactic classification from the TYN SC 2.03 dataset is shown for the four SRES scenarios (A1F1, A2, B1, B2) in 25-year time segments of 2001-2025, 2026-2050, 2051-2075, and 2076-2100 respectively (Figures 4-4 to 4-7) and pixel summaries for all scenarios are summarized in Table 4-4. Comparing the different maps of each of these figures with each other clearly shows the process of changes and displacement of climatic zones of Zayandehrud watershed, which is projected to occur due to climate change in different periods of the 21st century.

In the A1F1 scenario from 2001-2025 to 2026-2050, pixels 2, 8, 17, 18, 23, and 25 had climate change, but the significant difference was in climate change in pixels 8 and 2. In Pixel 8, a snowy climate with dry, very hot summers (Give K-G abbreviation) will turn into a temperate climate with dry, very hot summers (K-G abbreviation), and in Pixel 2, it will change from a dry, cold desert (K-G class) to a dry, very hot desert (K-G class). In the same scenario, from 2001-2025 to 2051-2075, the most drastic changes will be in Pixel 3 where conversion from temperate with dry, very hot summers (K-G class) to dry, cold semi-arid climate (K-G class) is observed and Pixel 8 where conversion from snowy with dry, very hot summers (K-G class) to temperate with dry, hot summers climate (k-G class) is observed. Finally, from 2001-2025 to 2076-2100, the most obvious changes will be in Pixel 8 (conversion from Dsa to Bsk) and Pixel 14 (conversion from Csa to Bsk).

In A2 scenario, from 2001-2025 to 2026-2050, Pixel 8 shows the most obvious changes (from Dsa to Csa). In this scenario, from 2001-2025 to 2051-2075, pixels 3 (conversion from Csa to Bsk) and 8 (from Dsa to Csa) have the most changes, and from 2001-2025 to 2076-2100, the most obvious changes will be in Pixel 8 (conversion from Dsa to Bsk).

In B1 scenario, which is the most optimistic scenario, pixels 3, 8, and 14 (conversion from Bsk to Csa) from 2001-2025 to 2026-2050, pixels 8 and 14 (conversion from Bsk to Csa) from 2001-2025 to 2051-2075, as well as from 2001-2025 to 2076-2100, will change.

In B2 scenario, in three 25-year time periods, changes will be in pixels 8 (conversion from Bsk to Csa) 26 (conversion from Csa to Bsk).

Table 4-4 Changed pixel number in different Scenarios

Climate types in the end time period	Climate types in the time period of origin	Changed pixel number	Scenario	Time period	No
Bwh	Bwk	2	A1F1	From (2001-2025) to (2026-2050)	1
Csa	Dsa	8	A1F1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	17	A1F1	From (2001-2025) to (2026-2050)	
Bwh	Bwk	18	A1F1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	23	A1F1	From (2001-2025) to (2026-2050)	
Bwh	Bwk	25	A1F1	From (2001-2025) to (2026-2050)	
Bwh	Bwk	2	A1F1	From (2001-2025) to (2051-2075)	
Bsk	Csa	3	A1F1	From (2001-2025) to (2051-2075)	2
Bsh	Bsk	5	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	7	A1F1	From (2001-2025) to (2051-2075)	
Csa	Dsa	8	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	11	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	12	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	13	A1F1	From (2001-2025) to (2051-2075)	
Bsh	Bwk	17	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	18	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	20	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	23	A1F1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	25	A1F1	From (2001-2025) to (2051-2075)	
Bsh	Bsk	28	A1F1	From (2001-2025) to (2051-2075)	
Bsh	Bsk	1	A1F1	From (2001-2025) to (2076-2100)	3
Bwh	Bwk	2	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	4 and 5	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bwk	6	A1F1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	7	A1F1	From (2001-2025) to (2076-2100)	
Bsk	Dsa	8	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	10	A1F1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	11, 12 and 13	A1F1	From (2001-2025) to (2076-2100)	
Bsk	Csa	14	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	15 and 16	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bwk	17	A1F1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	18 and 20	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	22	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bwk	23	A1F1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	25	A1F1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	27 and 28	A1F1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	2	A2	From (2001-2025) to (2026-2050)	4
Csa	Dsa	8	A2	From (2001-2025) to (2026-2050)	
Bsk	Bwk	17	A2	From (2001-2025) to (2026-2050)	
Bsk	Bwk	22	A2	From (2001-2025) to (2026-2050)	
Bsk	Bwk	23	A2	From (2001-2025) to (2026-2050)	
Bwh	Bwk	25	A2	From (2001-2025) to (2026-2050)	
Bwh	Bwk	2	A2	From (2001-2025) to (2051-2075)	
Bsk	Csa	3	A2	From (2001-2025) to (2051-2075)	

Csa	Dsa	8	A2	From (2001-2025) to (2051-2075)	5
Bwh	Bwk	11	A2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	12	A2	From (2001-2025) to (2051-2075)	
Bwk	Bsk	17	A2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	18	A2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	20	A2	From (2001-2025) to (2051-2075)	
Bsk	Bwk	22	A2	From (2001-2025) to (2051-2075)	
Bsk	Bwk	23	A2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	25	A2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	2	A2	From (2001-2025) to (2076-2100)	6
Bsh	Bsk	5	A2	From (2001-2025) to (2076-2100)	
Bsh	Bwk	6	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	7	A2	From (2001-2025) to (2076-2100)	
Bsk	Dsa	8	A2	From (2001-2025) to (2076-2100)	
Bsh	Bsk	10	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	11	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	12	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	13	A2	From (2001-2025) to (2076-2100)	
Bsh	Bsk	16	A2	From (2001-2025) to (2076-2100)	
Bsh	Bwk	17	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	18	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	20	A2	From (2001-2025) to (2076-2100)	
Bsk	Bwk	22	A2	From (2001-2025) to (2076-2100)	
Bsh	Bwk	23	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	25	A2	From (2001-2025) to (2076-2100)	
Bsh	Bsk	28	A2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	2	B1	From (2001-2025) to (2026-2050)	7
Csa	Bsk	3	B1	From (2001-2025) to (2026-2050)	
Csa	Bsk	8	B1	From (2001-2025) to (2026-2050)	
Csa	Bsk و Csa	14	B1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	17	B1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	18	B1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	22	B1	From (2001-2025) to (2026-2050)	
Bsk	Bwk	23	B1	From (2001-2025) to (2026-2050)	
Bsk و Bwh	Bwh	24	B1	From (2001-2025) to (2026-2050)	
Bwh	Bwk	25	B1	From (2001-2025) to (2026-2050)	
Bwh	Bwk	2	B1	From (2001-2025) to (2051-2075)	8
Bsk	Csa	3	B1	From (2001-2025) to (2051-2075)	
Bwk	Bsk و Bwk	6	B1	From (2001-2025) to (2051-2075)	
Csa	Bsk و Csa	8	B1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	11	B1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	12	B1	From (2001-2025) to (2051-2075)	
Csa	Bsk و Csa	14	B1	From (2001-2025) to (2051-2075)	
Bwk	Bsk و Bwk	17	B1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	18	B1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	20	B1	From (2001-2025) to (2051-2075)	
Bsk	Bsk و Bwk	22	B1	From (2001-2025) to (2051-2075)	
Bsk	Bwk	23	B1	From (2001-2025) to (2051-2075)	
Bwh	Bwk	25	B1	From (2001-2025) to (2051-2075)	

Bwh	Bwk	2	B1	From (2001-2025) to (2076-2100)	9
Bsk	Bsk و Csa	3	B1	From (2001-2025) to (2076-2100)	
Csa	Bsk و Csa	8	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	11	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	12	B1	From (2001-2025) to (2076-2100)	
Csa	Bsk و Csa	14	B1	From (2001-2025) to (2076-2100)	
Bsk	Bwk	17	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	18	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	20	B1	From (2001-2025) to (2076-2100)	
Bsk	Bsk و Bwk	22	B1	From (2001-2025) to (2076-2100)	
Bsk	Bsk و Bwk	23	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	25	B1	From (2001-2025) to (2076-2100)	
Bsh	Bsk	28	B1	From (2001-2025) to (2076-2100)	
Bwh	Bwk	2	B2	From (2001-2025) to (2026-2050)	10
Csa	Dsa	8	B2	From (2001-2025) to (2026-2050)	
Bsk	Bwk	17	B2	From (2001-2025) to (2026-2050)	
Bsk	Bwk	23	B2	From (2001-2025) to (2026-2050)	
Bwh	Bwk	25	B2	From (2001-2025) to (2026-2050)	
Bsk	Csa	26	B2	From (2001-2025) to (2026-2050)	
Bwh	Bwk	2	B2	From (2001-2025) to (2051-2075)	11
Csa	Dsa	8	B2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	18	B2	From (2001-2025) to (2051-2075)	
Bsk	Bwk	23	B2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	25	B2	From (2001-2025) to (2051-2075)	
Bsk	Csa	26	B2	From (2001-2025) to (2051-2075)	
Bwh	Bwk	2	B2	From (2001-2025) to (2076-2100)	12
Csa	Bsk	4	B2	From (2001-2025) to (2076-2100)	
Bsk	Bwk	6	B2	From (2001-2025) to (2076-2100)	
Csa	Dsa	8	B2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	11	B2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	12	B2	From (2001-2025) to (2076-2100)	
Bsh	Bwk	17	B2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	18	B2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	20	B2	From (2001-2025) to (2076-2100)	
Bsh	Bwk	23	B2	From (2001-2025) to (2076-2100)	
Bwh	Bwk	25	B2	From (2001-2025) to (2076-2100)	
Bsk	Csa	26	B2	From (2001-2025) to (2076-2100)	
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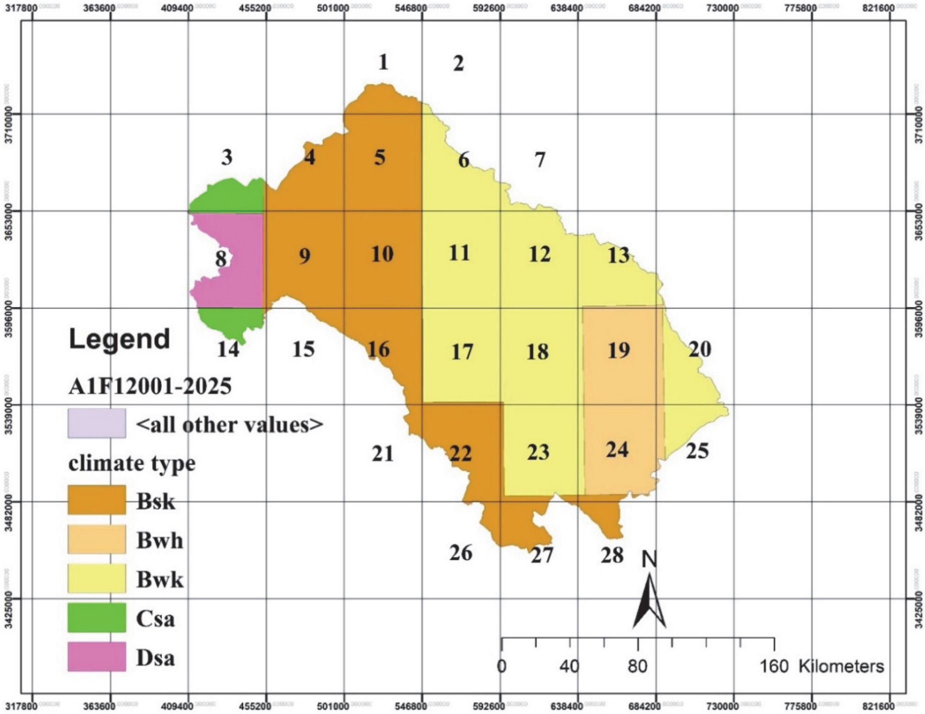
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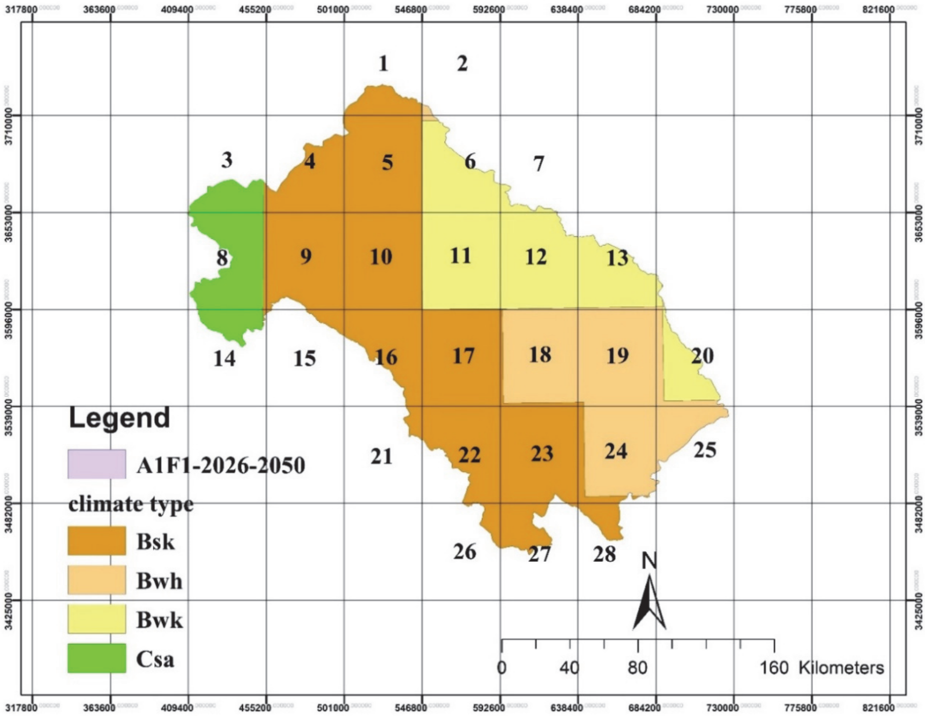
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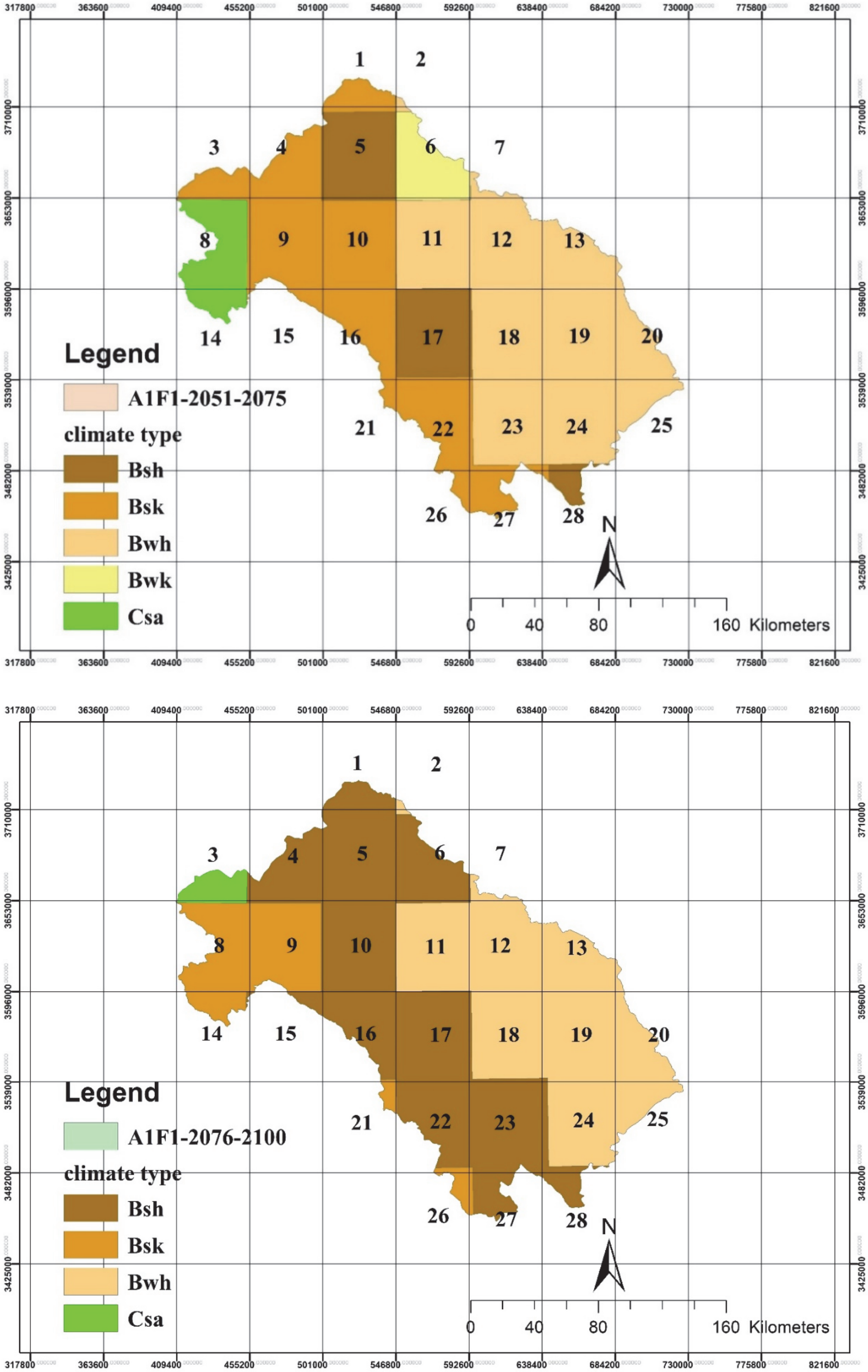
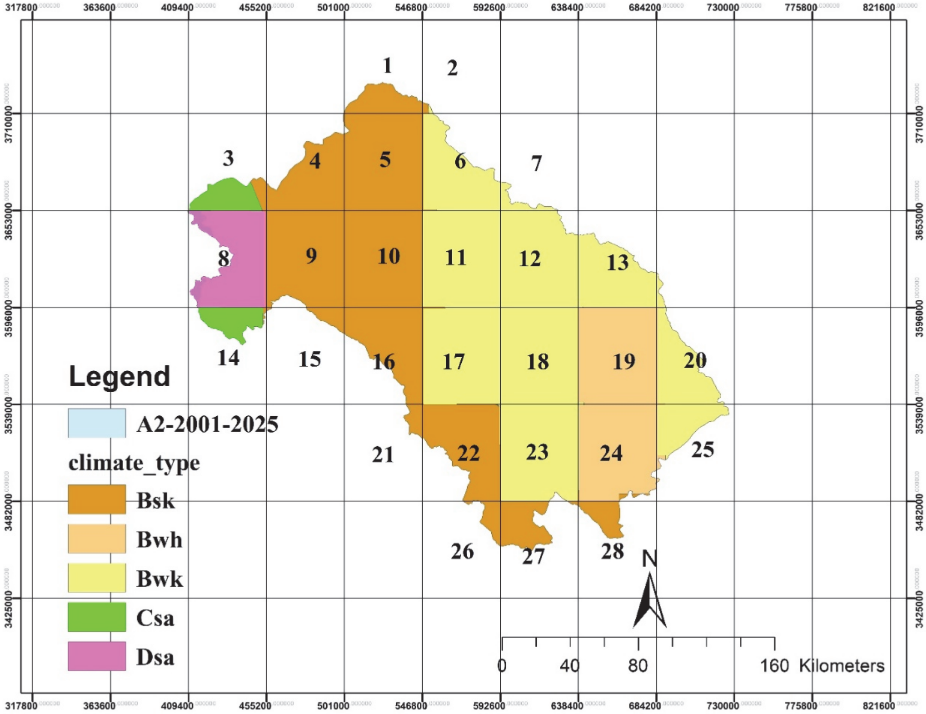


Figure 4-4 Predicting climate classification in the 21st century under the A1F1 scenario (Adapted by authors from Rubel and Kottek, 2010)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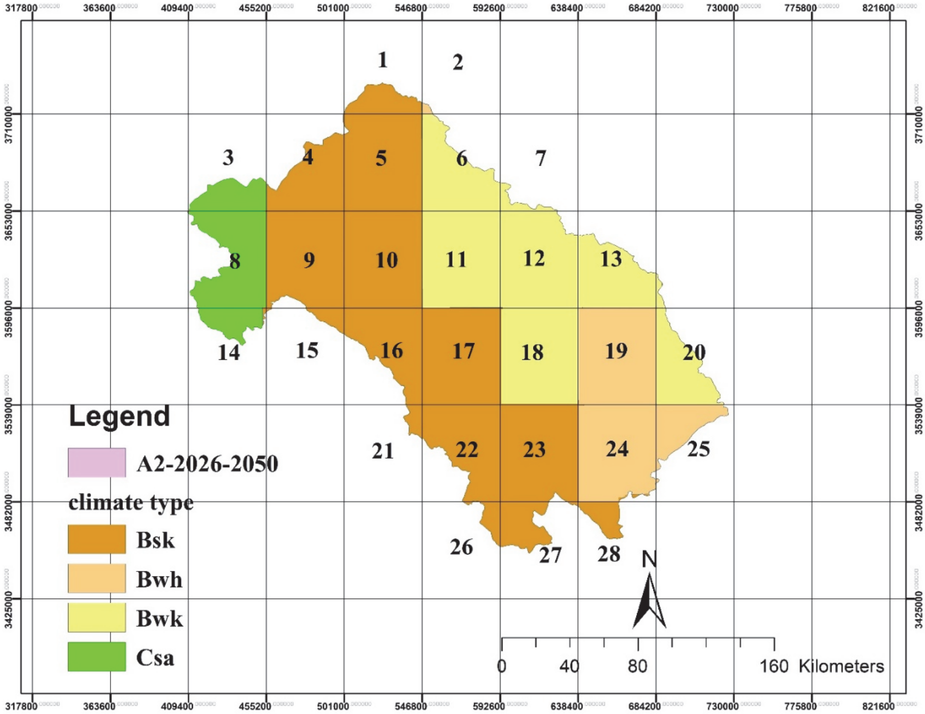
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Bwk
Csa
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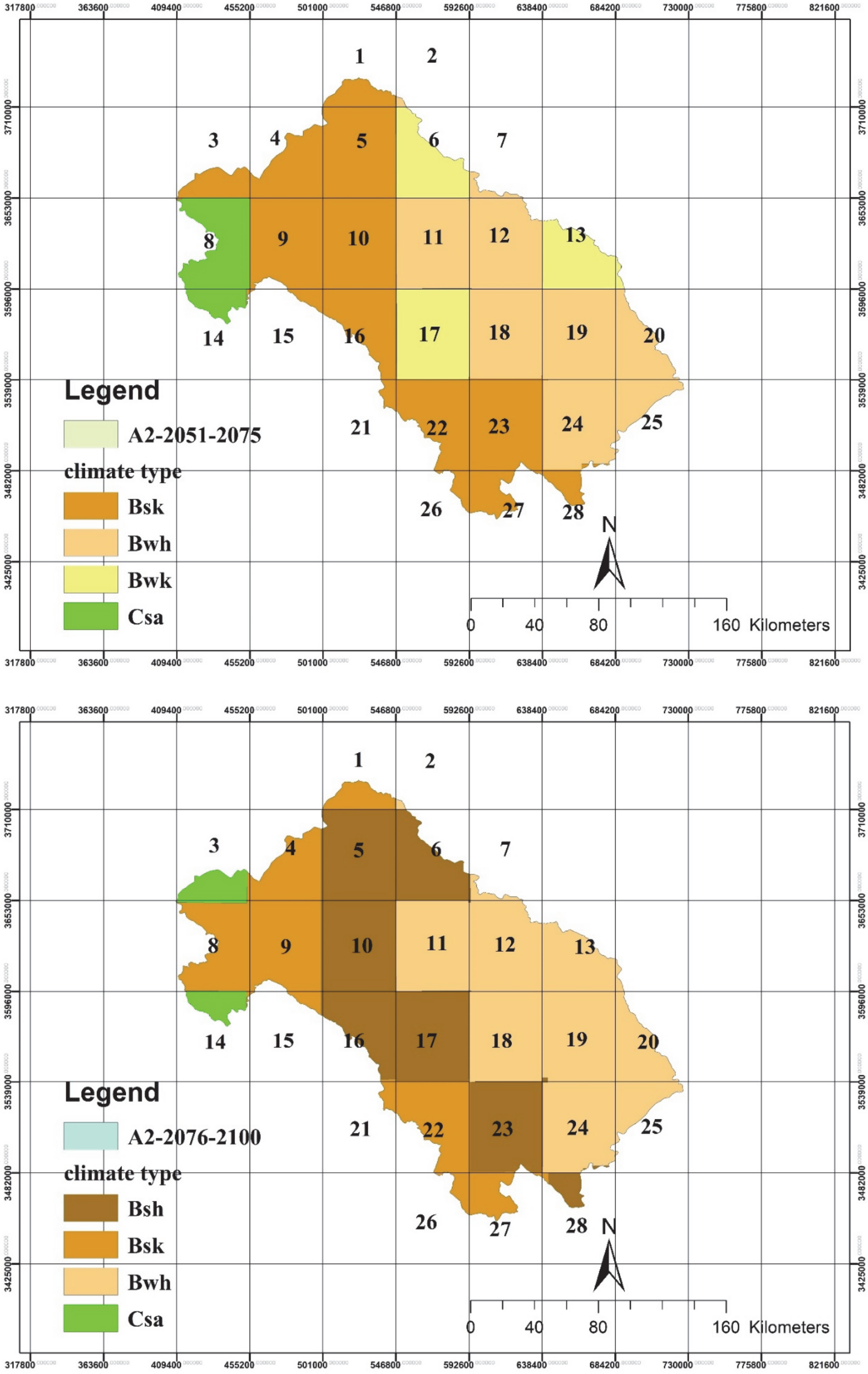
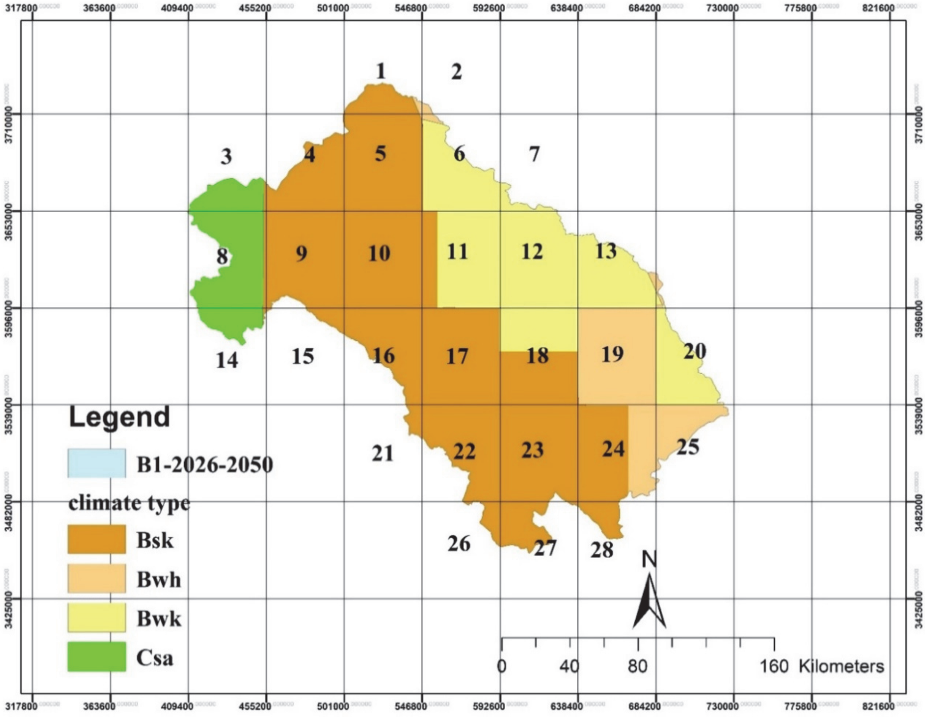


Figure 4-5 Predicting climate classification in the 21st century under the A2 scenario (Adapted by authors from Rubel and Kottek, 2010)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Legend
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Bwk
Csa
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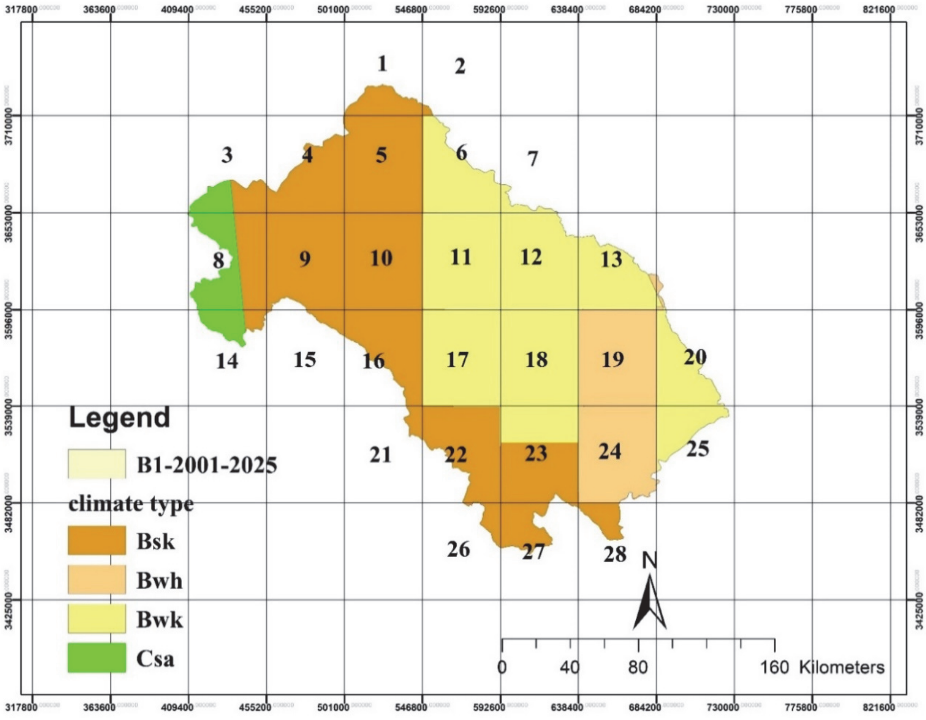
80
160 Kilometers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Legend
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climate type
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160 Kilometers

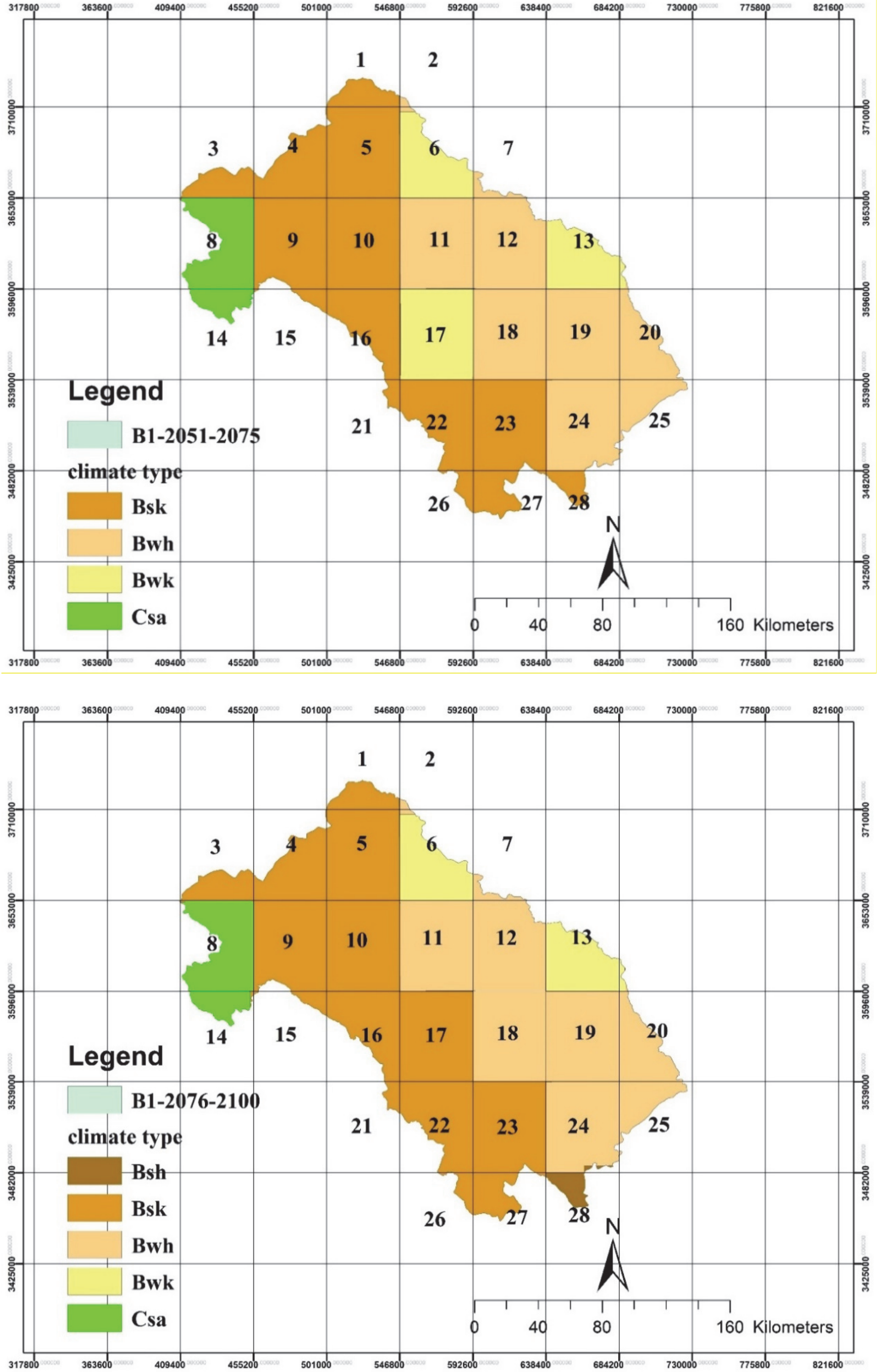
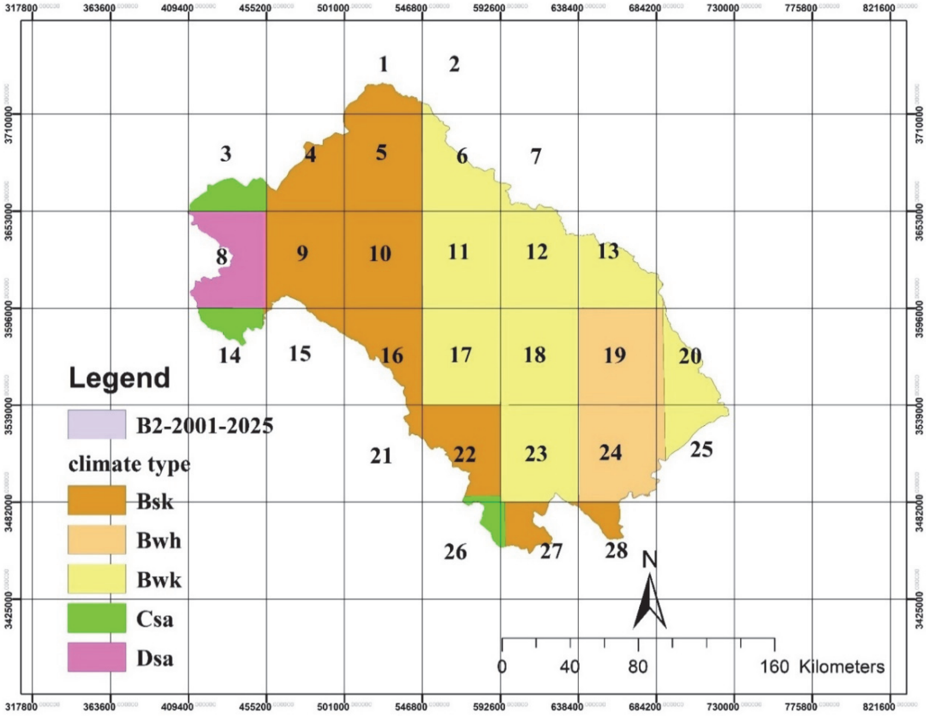


Figure 4-6 Predicting climate classification in the 21st century under the B1 scenario (Adapted by authors from Rubel and Kottek, 2010)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Legend
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climate type
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Bwh
Bwk
Csa
Dsa
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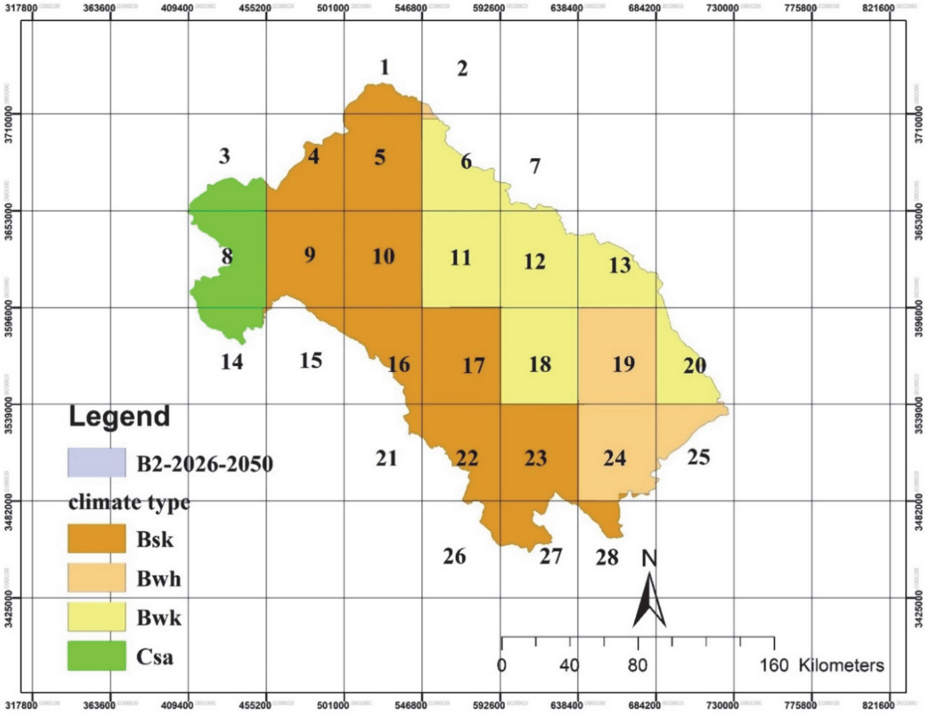
160 Kilometers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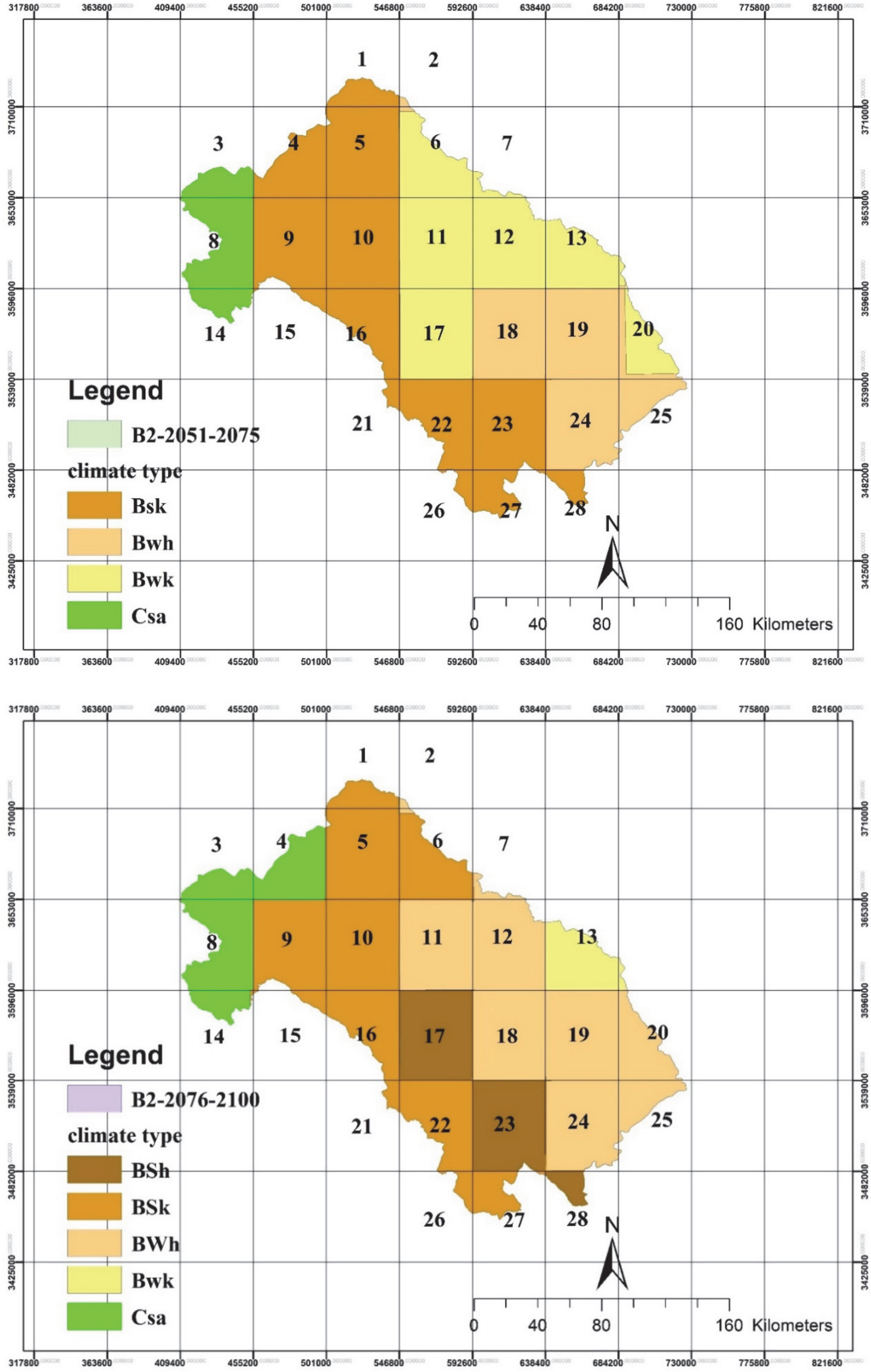

Figure 4-7 Predicting climate classification in the 21st century under the B2 scenario (Adapted by authors from Rubel and Kottek, 2010)

4. Discussion

Examination of the SRES scenarios in four 25-year periods of 2001-2025, 2026-2050, 2051-2075, and 2076-2100 indicates that many parts of Zayandehrud watershed will be affected by climate change in the 21st century. In general, the situation in this region will progress towards becoming warmer and arider than it currently is. The most dramatic climatic changes observed will occur at upstream and downstream stations. Changes at higher elevations in the watershed indicate that snowy climate classes in mountainous regions (K-G class D) will be displaced more than any other climatic group. Rubel and Kottek (2010) predict that the snowy climatic group (K-G class D) will be replaced by the drier and warmer climate groups C and B. Using General Circulation Models (GCM), Kouhestani et al. (2017) concluded that in the northwestern regions of Zayandehrud watershed (upstream), the biggest changes in minimum and maximum temperatures would occur, leading to a decrease in snow reserves in the west and northwest of this region. Hasheminasab et al. (2019) also concluded both upstream and downstream areas of Zayandehrud watershed, composed of different climate groups, sub-groups, and sub-divisions has been affected by the drought, especially since the upstream parts of the watershed are more affected by climate parameters changes than the other parts, due to the more humid climate. Therefore, it is necessary to study these conditions and pay attention to it for planning and management of water resources in the coming years, considering the emerging expectation of surface water shortages. Most importantly, local studies from Kouhestani et al. (2017) and Hasheminasab et al. (2019) confirm the predictive modeling a decade ago from Rubel and Kottek (2010) and indicate that the case study area is on the A1F1 SRES trend.

In the present study, the most significant change in climate type is in Pixel 8 (Fereydun Shahr), which is more evident in pessimistic scenarios (A1F1 and A2) and from the period 2001-2025 to 2026-2050 (from Dsa to Csa) and also from 2051-2075 to 2076-2100 (from Csa to Bsk). Masah Bouani and Morid (2005) also predicted significant changes in Zayandehrud watershed in Fereydun Shahr station in the period of 2010-2039, which is consistent with the results of the present study.

5. Conclusion and Recommendations

The results of this study indicate the climate change of upstream regions from Dsa to Csa climate classification from 2001-2025 to 2026-2050 and also change of Csa to BW from 2051-2075 to 2100-2076, if the process of using fossil fuels and economic growth continues. Therefore, regarding the phenomenon of global warming and the predictions, it is necessary to make regional and national plans for its management. Correct knowledge of the effects of climate change is an essential factor in the preparation of adaptive climate change planning.

Climate change planning has often fallen into one of two strategies: mitigation efforts to lower or remove greenhouse gas emissions from the atmosphere or adaptation efforts to adjust systems and societies to withstand the impacts of climate change. Mitigation has a long-term effect on climate change, while adaptation can have a short-term effect on the reduction of vulnerable populations (Locatelli et al., 2011).

5.1 Mitigation Strategies

Mitigation measures that could be considered for the Zayandehrud watershed given the expected climate changes include protecting existing and expanding forest vegetation in order to sequester atmospheric carbon, incentivizing forest land conservation such as Reducing Emissions from Deforestation and forest Degradation project (REDD) that provides financial incentives to preserve forests and thus maintain carbon stocks in forest ecosystems (Turner et al., 2009; Angelsen 2008). Investing in urban mass transit systems can reduce per capita vehicle miles traveled, and other transportation technologies such as hybrid and plug-in hybrid electric vehicles, intelligent transport systems, and low-emissions aircraft could be effective at climate change mitigation (SBSTA, 2006). Hergoualc'h et al. (2012) suggested agroforestry is an opportunity to reduce CO2 concentrations in the atmosphere by increasing above and below ground carbon (C) stocks in agricultural lands. Promotion of mineral N fertilization and the use of N2-fixing legumes that favor the emission of non-CO2 greenhouse gases (GHG) (N2O and CH4) could also be a land management strategy to reduce agricultural-based emissions that come from green water exchange during photosynthesis. Recycling of organic wastes into organic fertilizer and investment in N or P fixation technologies in municipal wastewater treatment systems can also reduce reliance on industrially produced fertilizers that contain C02 emissions in their production life cycle and provide local sources for organic fertilizers (Lawrence 2019). Finally, an increase in the share of renewable electricity generation (Lowwind speed turbines, advanced bio-refineries, Cellulosic biofuels, Community-scale solar systems, Water photolysis, and Genetically engineered biomass) and reducing the share of natural gas or oil-powered electricity generation can also change the carbon balance related to electricity supply and demand (Lawrence 2019). Given the expansion of the B climate group, the application of photovoltaic electricity in settlement adjacent uninhabited lands of low agricultural productivity or without use as grazing lands would be a logical choice to secure local energy supply.

5.2 Adaptation Strategies

Climate change adaptation strategies that could be considered for the Zayandehrud watershed given the expected increases in temperature, reduction in precipitation, and summertime river base flow include strategies to adapting building codes to demand new building technologies such as “smart” buildings to efficiently cool human dwellings with minimum energy use and to keep that cooling in via insulating measures, such as the German program of “energetische Sanierung” (Weißermel, S., & Wehrhahn, R 2020). Reduction of the urban heat island effect can also cool the layer of atmosphere closest to the ground in which humans live, and programs for the estimation of urban heat islands and their vulnerable populations are well developed (Ketterer and Matzarakis 2015; Dugord et al., 2014; Leal Filho et al., 2018) and should be applied to Esfahan. Indeed traditional Persian gardens composed of massive stone buildings enclosing a tree-shaded courtyard shaded with a fountain to increase evapotranspiration and thereby cool the ambient air temperature could also help reduce heat island effects. Given the increase in summer water scarcity, competition for domestic water resources will also likely increase in the future. Consequently, policies for the reduction of domestic water consumption per capita and increases in supply and treatment efficiency measures will become essential. The United States EPA National Pollution Discharge Elimination System (NPDES), for example, includes the separation of stormwater and greywater subsurface piping in urban areas with over 100,000 people to facilitate pollution treatment and nutrient recapture of water in the urban system. NPDES is wrapped into a regulatory compliance framework to monitor and require such efficient investments in municipal water management (US EPA, 2020). Section 502 of the US Clean Water Act also allows the implementation of green stormwater infrastructure that includes vegetation and soil-based infiltration measures to reduce the need for large scale detention or flooding via the implementation of small scale decentralized rainwater detention. This system is analogous to the German program of ‘Dezentrale Regenwasserbewirtschaftung’ (decentralized rainwater management) (Schuetze 2013). Examples of decentralized rainwater management that implement traditional terrace formations in Duhok, a similar climate zone (Csa) experiencing increases in temperature and elongated dry seasons in north Iraq (Lawrence et al., 2019), maybe transferrable to urbanized areas in the Zayandehrud watershed.

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