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ORIGINAL PAPER

A survey on the Koppen climate classification of Iran in 1975 and Comparing it with the CSIR Model Outputs for the years 2030, 2050, 2080 and 2100 under the A1B and A2 Scenarios

Hadis Kiani[1] · Muhammad Kamangar[1]

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Abstract

The increasing greenhouse gas emissions and its consequences, as climate change and global warming have many subsequences for the earth. One of these consequences, particularly for areas of the world that is located in the warm and arid belts, is the increase in arid and semi-arid climate-covered areas. In this study, the Koppen climate classification of Iran in 1975 is compared with the CSIR model outputs classification for the years 2030, 2050, 2080, and 2100 under the two scenarios A1B and A2 which can be found in the Fourth Assessment Report of the IPCC. The Koppen climate classification method categorizes climatic zones based on temperature, precipitation and vegetation. The Koppen method is one of the most widely used climatic classification methods. The results of this study have revealed that in 1975, 82.3% of the country was covered by subgroup B climates, 5.9% was covered by subgroup C and 11.8% was covered by subgroup D climates. However, under both scenarios, the extent of subgroup B climates will increase in the future; so that in 2030, the extent of these areas will reach more than 87%, in 2050 to more than 90%, in 2080 to more than 93% and in 2100 to more than 94%. Generally, the results show a gradual increase in areas covered by warm and arid climates and a decrease in the extent of cold and temperate climates in Iran over the coming years by 2100.

Keywords Climate Classification · The CSIR Model · Climate Change

Introduction

The climate is a general condition of the prevailing weather conditions of a given location based on long-term statistics (Montazeri and Bai 2012; Ostad-Ali-Askar et al 2018). The variety of climatic elements is effective in determining the climate of a given area and it causes the formation of diverse climates (Hedayati and Kakavand 2012; Ostad-Ali-Askar et al 2019; Javadinejad et al. 2021). A comparison of the recorded climate characteristics in different locations on earth indicates significant differences on the planet's surface; therefore, each location has some unique features.

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✉ Hadis Kiani
hadiskiani3865@gmail.com

Muhammad Kamangar
Muhammad.Kamangar@znu.ac.ir

[1] University of Zanjan, Zanjan, Iran

Understanding weather and eventually climate has always been one of the most important matters that interested the mankind such a long time and of course have been of great importance in today's human life. Understanding the natural features of every area, especially the climate, can play a major role in the planning for the land and preparing it (Tavosi and Delara 2010; Ostad-Ali-Askar et al. 2020). In order to achieve this goal, climatic zoning is required so different areas can be identified in climatic terms. From a geographical perspective, climatic zoning means classifying and categorizing climatic zones in a way that each region has similar climatic characteristics (Mahdavian et al. 2002; Talebmorad et al 2021), on the other hand, increasing greenhouse gas emissions and its consequences, have led to global warming and climate change (Saleh Pourjam et al. 2015; Ostad-Ali-Askar and Shayannejad 2021). Climate change is the long-term and irreversible atmospheric conditions that occur over decades or even millions of years in a region's climate. According to the recorded data, from 1901 to 2012, the mean temperature of the earth and ocean's surface has risen about 0.89 degrees Celsius (Taei

Semiromi et al. 2015). According to NOAA's 2020 Annual Climate Report the combined land and ocean temperature has increased at an average rate of 0.13 degrees Fahrenheit (0.08 degrees Celsius) per decade since 1880 (https://www.ncdc.noaa.gov/sotc/global/202013).

Accordingly, changes in the climate of different regions of the world and shifting in boundaries of the existing climate zones is expected. In Iran, due to its wide latitudes and different local conditions in different regions with such various climates, the matter of climatic zoning has been highlighted. On the other hand, because of Iran's position on the world's warm and arid belt, it has been affected by global warming and climate change. Therefore, it is necessary to examine the new climate conditions of the country as well as the possible displacements of the existing boundaries of climatic zones. Although the impacts of climate change on the displacement of the climate boundaries is a new topic that has not been extensively studied, some studies related to them have been conducted globally and also in Iran, particularly on climate change and climate classifications, for example: Global climate change was specified using the climate classification of Koppen (Beck et al 2005). In Australia, rivers in tropical areas are classified to predict climate change impacts (Erskine et al 2006). De Castro et al. (2007) examined the effects of climate change in Europe using climate classification and the output of climate models. Future changes in climate zones in Australia have also been examined (Crosbie et al. 2012). Chen and Chen (2013) used the Koppen climate classification to examine the extent of global climate change during the period 1901–2010. Belda et al. (2014) in a study using the Koppen-Trewartha and Koppen methods examined the changes in climate zones. An assessment of Georgia's vulnerability due to climate change is also a study conducted on this topic (Binita et al 2015). The effect of climate change on the amount of water available in semi-arid regions in central Mexico has been studied (Pantoja and Hiskuk 2015). In also, Beck et al. (2018) compared the present and future climate based on the Koppen classification method under the RCP 8.5 scenario. In Iran, climatic-radiation classification of country, climate zoning of country, Ardabil and Qazvin Provinces, also the Khazar area has been done using synoptic stations data (Jafarpoor and Karshenas 1999; Heydari and Alijani 2000; Tavosi and Delara 2010; Hedayati and Kakavand 2012; Montazeri and Bai 2012). In another study, the classification of homogeneous climatic regions under the impact of climate change greenhouse gas emission scenarios in Iran has been performed (Mohammadipour and Malekinezhad 2014). The Impact of climate change on Iran's water resources has also been studied (Shokoohi et al. 2014). Changes in some climate variables are predicted using downscaling model LARS-WG, under different scenarios (Taei Semiromi et al. 2015). Bahri et al. (2015) examined the effect of climate change on droughts in the period 2011–2030 in Eskandari basin. Mirmousavi and Kiani (2017) examined the changes in the boundaries of Iran's climatic zones in the coming decades using the outputs of the MIROC model.

In this study, the climate of Iran is assessed on the basis of the Koppen climate classification for the past years and is compared with the coming years based on CSIRO-MK3 model outputs. Whereas the Koppen climate classification was developed based on the empirical relationship between climate and vegetation (Chen and Chen 2013); it can be used effectively to identify changes in climate zones. This is also the first time that CSIRO-MK3 model outputs are used to assess climate change in Iran.

The study area

The study area of this survey is Iran, which is located in the range from 25 degrees 3 min to 39 degrees 47 min north latitude and 44 degrees 5 min to 63 degrees 18 min east longitude. Iran is one of the southwest Asia (Middle East) countries. Its neighboring countries and waters are Afghanistan and Pakistan in the east; Turkmenistan in the northeast; the Caspian Sea in the north; the Republic of Azerbaijan and Armenia in the northwest; Turkey and Iraq in the west; and finally are the waters of the Persian Gulf and the Oman Sea in the south. Iran has two main mountains range that surrounding central areas. Zagros Mountains that bisect the country from northwest to southeast and Alborz mountains that stretch from northwest to northeast. The geographical location and topography of Iran has caused this country to have various climates. Figure 1 shows Iran's position in the Middle East region.

Materials and Methods

In this study, the Koppen climate classification data of 1975 were used as the base year. Also, the data simulated using the two atmosphere–ocean models CSIRO-MK3 presented in the fourth (AR4) IPCC report, under two scenarios A1B and A2, for the years 2030, 2050, 2080, and 2100 will be used to examine future changes. In this way, the results of Koppen classification based on simulated data were compared and evaluated with the base year. The details about the CSIRO-MK3 model are presented in Table 1.

This model was designed in collaboration with the National Institute for Environmental Studies (NIES), the Atmosphere Ocean Research Institute (CCSR) University of Tokyo and Japan Agency for Marine-Earth Science and Technology for the twenty-first century climate prediction, with relatively high elaboration and resolution. Compared to models such as the HadCM3 ($3.75° \times 2.5°$ atmosphere

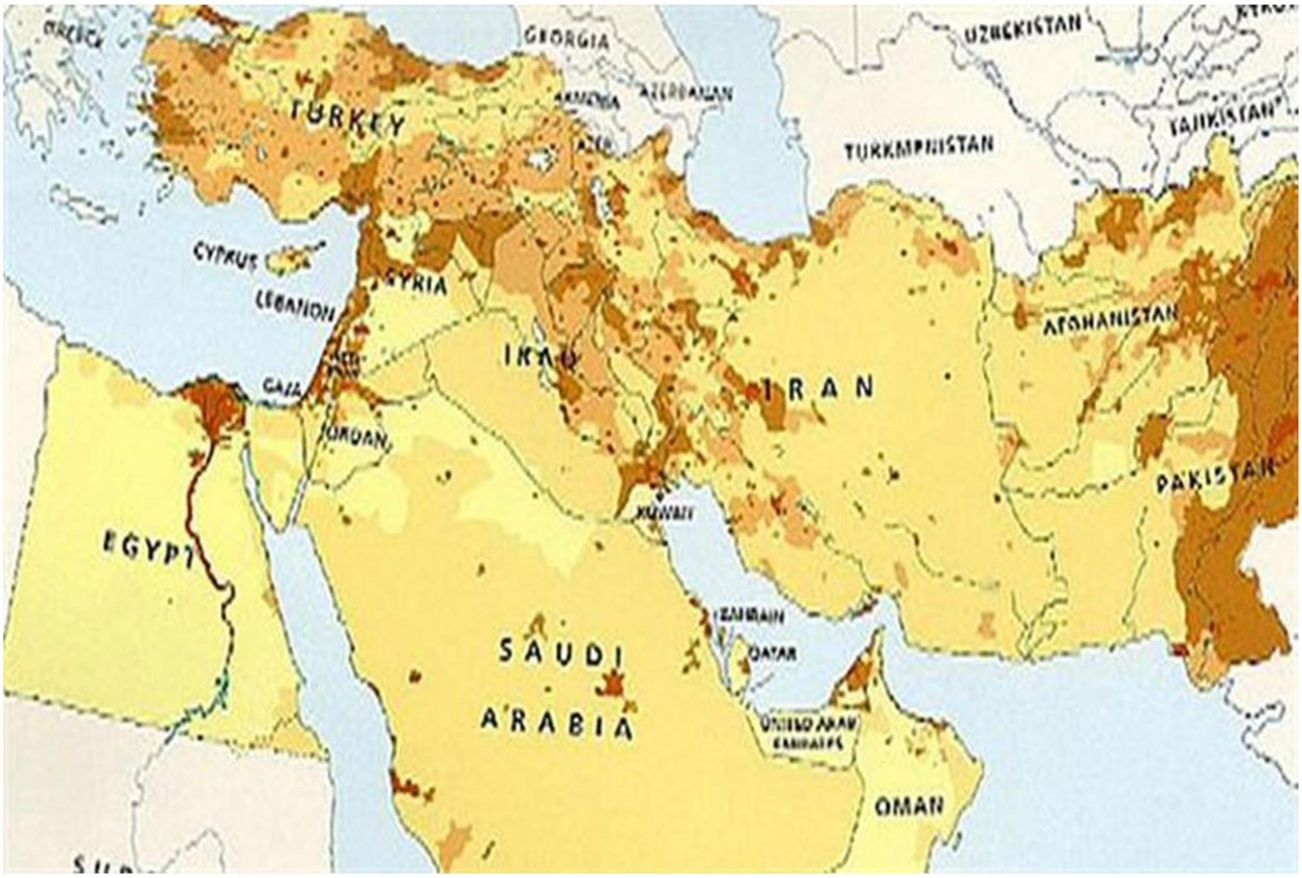

Fig. 1 Iran's position in the Middle East region

Table 1 The details about the CSIRO-MK3 model in the AR4 report

The model name	Atmospheric resolution	Oceanic resolution	Simulation scenarios
CSIRO-MK3	1.9° × 1.9°	0.8° × 1.9°	A1B, A2

Source: IPCC Fourth Assessment Report (AR4) (2007).

resolution and of 1.25° × 1.25° oceanic resolution), this has a higher resolution.

The atmospheric predictor variables in this model include temperature, the north and east wind component and surface pressure, and the oceanic predictor variables include orbital and meridional wind velocity, temperature, salinity and above sea level. The information about the scenarios used in this model is summarized in Table 2.

Although the Koppen method for climate classification seems simple, it has been widely used for climatic zoning and detection of changing of climate zones.

In 1918, based on the monthly, annual temperature and precipitation, and the distinct vegetation units, Koppen divided the Earth into several climatic units and comprises the following main groups:

Climate Group A: tropical climate and without winter.

Climate Group B: arid and semi-arid climate with little precipitation.

Climate C: temperate climate and mild winter.

Climatic Group D: cold climate and cold winter.

Table 2 Details about A1B and A2 emission scenarios

Scenario A2	A1B scenario
Diverging World (regionalization) regional economic development Temperature increase (2 to 5.4 degrees)	The Converged World (Globalization) Rapid economic growth (A1T, A1FI and A1B) Temperature increase (1.4 to 6.4 degrees)

Source: A Special Report of IPCC Working Group III (2000).

Climate Group E: polar climate and no summer (Alijani and Kaviani 1992).

In this study, in the first step, a map of Iran's climatic zones in 1979 was prepared based on observational data. In the second step, maps of the country's climatic zones in 2030, 2050, 2080, and 2100 were prepared based on simulated data, and in the next step, future changes compared to the base year were examined.

Results

The Koppen climate classification for Iran in 1975

Figure 2 shows the Koppen's climatic classification for Iran in 1975. According to this classification, Iran's climate in 1975 consisted of 3 primary groups B (arid and semi-arid with little precipitation), C (temperate with mild winter) and D (cold with cold winter, temperature of coldest month less than -3 degree) and subgroups of these three groups. As can be seen in Fig. 2 and Table 3, in general, group B climates occupy the largest area of the country. In B climate subgroups, the BWH ($T \geq 18^{\circ}c$) climate, which represents warm and dry climates, covers about 40% (641043.7 km^2) of the total country. These areas include large parts of the center, south, southeast and southwest. The BSK, which represents the semi-arid and cold climate, covers 22% of the northeast areas, Alborz and eastern slopes of Zagros Mountains. The BWK climate, which covers 15.4% of the entire country, is placed in the margins of the central Iran and parts of the east and southeast. The CSA subgroup, which represents the Mediterranean climate, is found in about 6% of the country. It covers some areas in the north, northwest, west and western Zagros Mountains. The cold climates of Group D are found in the western and northwestern mountainous regions of Iran, covering about 12% of the country.

Table 3 Types of Iran's climatic groups, the extent and coverage percentage of them based on the Koppen climate classification in 1975

Climatic Groups	Extent in Km^2	Extent in percentage
Bwk	252287	15.49866
Bwh	641043.7	39.38101
Bsk	362448.8	22.26619
Bsh	83479.68	5.128378
Cfa	3420.774	0.210147
Csa	92607.88	5.689147
Csb	651.8185	0.040043
Dfa	651.8185	0.040043
Dfb	6652.383	0.408673
Dsa	122045.2	7.497561
Dsb	62302.19	3.827388
Dsc	208.7084	0.012822

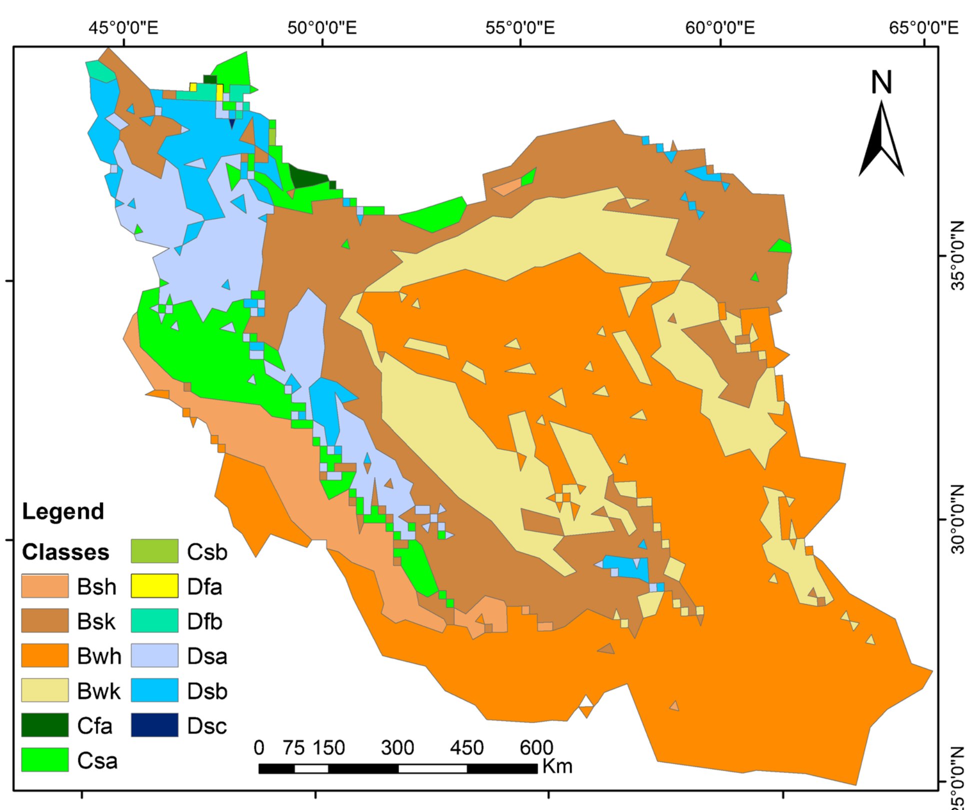

Fig. 2 Climatic map of Iran based on the Koppen climate classification in 1975

The Koppen climate classification in Iran based on CSIR model for the coming years

Maps of Koppen's climatic classification based on CSIR model for the years 2030 and 2050 for both scenarios (A1B and A2) illustrate the existence of the three primary climatic classes including B, D, and C (Fig. 3). This is while there have been changes in the extent of group B climates. This is while there have been changes in the extent of group B climates. In a way that the BWH subgroup with the warm and semi-arid climate, which was most extensive in the country in 1975, will increase by 10% in 2030 based on the A1B scenario and 9% on the A2 scenario. Also, by 2050, under the A1B scenario, the areas that cover with such climate will increase 15%, and under the A2 scenario 12%. This increase while the area of the other B subgroups in the country will decrease. In Group C, there will be a decrease of nearly 1% in 2030 under both scenarios compared to the base year and by 2050, this reduction will reach more than 1%. Group D, in 2030 under the A1B and A2 scenarios, will have a 6% and 4% reduction in coverage, respectively. This coverage decrease during 2050 is also visible. Table 4 shows the coverage of different climates for the years 2030 and 2050 under the two scenarios A1B and A2.

Figure 4 shows the Koppen climate classification maps for years 2080 and 2100 under both A1B and A2 scenarios. The Koppen climate classes boundaries will also have significant shifts over the two years compared with 1975 in a way that the BWH subgroup will increase by 21% in 2080 under the A1B scenario and 23% under the A2 scenario. In other words, in both scenarios, climate group B will cover more than 90 percent of the country. Also, subgroups C climates will decrease in the country and their diversity will disappear. The most decrease belongs to the Climate Group D, with their extent reaching from about 11% of the country to less than 2% in both scenarios compared to 1975. This trend will continue even more strongly in 2100, with a warm and arid climate covering 65% of the entire country under the A1B and 69% under the A2 scenario. Also, the temperate climate cover about 5% of the country under the A1B scenario, and less than 4% under the A2 scenario. Under both scenarios, the cold climate is observed in less than 1% of the country (Table 5).

Conclusion

In this study, we tried estimating Iran's climate change in the coming years using the Koppen climate classification method. For this purpose, the classification obtained from the observational data in 1975 has been compared with the classification based on the output of the CSIR model in the fourth IPCC evaluation report (AR4), under two scenarios A1B and A2, for 2030, 2050, 2080, and 2100.

The classification of model outputs shows that the areas covered by Group B climate will increase and the country's

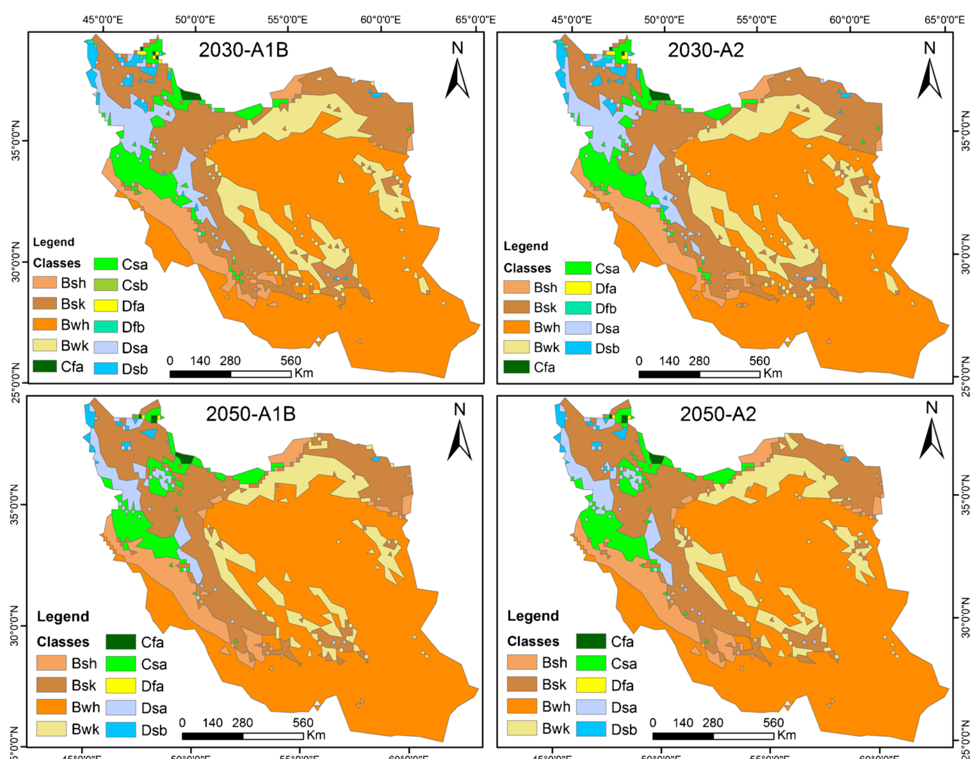

Fig. 3 the maps from CSIRO model for the years 2030 and 2050 under the two scenarios A1B and A2

Table 4 Types of climate groups from CSIR model in Iran and their extent and coverage percentage based on Koppen climate classification in 2030 and 2050 under A1B and A2 scenarios

2030 (A1B Scenarios)			2030 (A2 Scenarios)		
Climatic Groups	Extent in Km^2	Extent in percentage	Climatic Groups	Extent in Km^2	Extent in percentage
Bwk	196771.7	12.11078	Bwk	201387.7	12.3962
Bwh	798456.9	49.14291	Bwh	783542.2	48.23009
Bsk	351041.9	21.6057	Bsk	354826.6	21.84097
Bsh	90076.8	5.543989	Bsh	87393.05	5.379384
Cfa	4236.991	0.260776	Cfa	3968.92	0.244303
Csa	78541.05	4.833994	Csa	79526.37	4.895159
Csb	269.7345	0.016601	-	-	-
Dfa	1607.422	0.098933	Dfa	1874.534	0.115385
Dfb	1339.732	0.082457	Dfb	2144.943	0.13203
Dsa	81179.55	4.996387	Dsa	87712.23	5.399031
Dsb	21243.5	1.307481	Dsb	22216.11	1.367488
2050 (A1B Scenarios)			2050 (A2 Scenarios)		
Climatic Groups	Extent in Km^2	Extent in percentage	Climatic Groups	Extent in Km^2	Extent in percentage
Bwk	155850.4	9.59808	Bwk	174166.3	10.7216
Bwh	884517	54.47318	Bwh	833203.3	51.29163
Bsk	334964.6	20.62887	Bsk	364837	22.45921
Bsh	104077	6.409607	Bsh	101715.9	6.261583
Cfa	4283.143	0.263778	Cfa	4356.038	0.268156
Csa	76007	4.680908	Csa	70670.93	4.350471
Dfa	535.0747	0.032953	Dfa	2145.253	0.132061
Dsa	53196.48	3.276117	Dsa	55297.75	3.404105
Dsb	10335.55	0.636517	Dsb	4549.032	0.280036

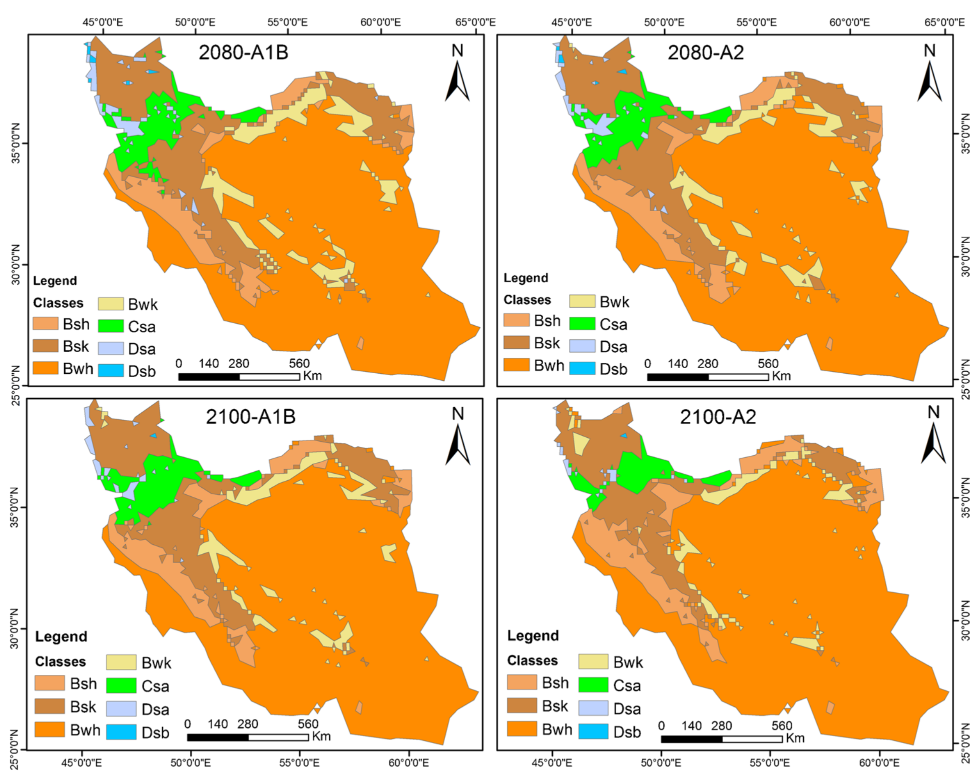

Fig. 4 The maps from CSIRO model for the years 2080 and 2100 under the two scenarios A1B and A2

Table 5 Types of climate groups from the CSIR model in Iran and their extent and coverage percentage according to the Koppen climate classification in 2080 and 2100 under the A1B and A2 scenarios

2080 (A1B Scenarios)			2080 (A2 Scenarios)		
Climatic Groups	Extent in Km^2	Extent in percentage	Climatic Groups	Extent in Km^2	Extent in percentage
Bwk	116783.9	7.185508	Bwk	99569.45	6.126065
Bwh	980502.3	60.32858	Bwh	1011463	62.23079
Bsk	298992.9	18.39651	Bsk	288159.8	17.72919
Bsh	118361.1	7.282548	Bsh	121582.7	7.480445
Csa	82729.75	5.090216	Csa	81526.87	5.015985
Dsa	25383.77	1.561819	Dsa	21245.67	1.307152
Dsb	2517.234	0.154881	Dsb	1794.186	0.110388
2100 (A1B Scenarios)			2100 (A2 Scenarios)		
Climatic Groups	Extent in Km^2	Extent in percentage	Climatic Groups	Extent in Km^2	Extent in percentage
Bwk	80966.64	4.983838	Bwk	62134.14	3.822468
Bwh	1053926	64.87357	Bwh	1122283	69.04241
Bsk	263898.8	16.24409	Bsk	231122.1	14.21854
Bsh	126894.6	7.810897	Bsh	147532	9.076111
Csa	84796.12	5.219559	Csa	55525.11	3.415883
Dsa	14439.15	0.888791	Dsa	6537.808	0.402203
Dsb	364.3046	0.022424	Dsb	364.3046	0.022412

climatic diversity will decrease in the future. These results are consistent with the findings of Chen and Chen (2013) also Mirmousavi and Kiani (2017).

The results of this study clearly show that a warm and dry climate (BWH class) will expand significantly in the coming years in Iran. This increase is such that in 2100 over 90% of the country covered by this climate under both scenarios. This is while the temperate climate of Group C, which represents the Mediterranean climate in Iran, can only be found in limited parts of the north and northwest coastal areas. Also, cold climates (group D) include only limited parts of the mountainous areas of the northwest of the country. Most changes and replacement of warm and dry climates with cold and temperate climates can be seen in the western and northern half of the country. Therefore, it can be expected that the central deserts of the country will be extended to the western and northern regions in the future. The occurrence of such changes can have many environmental, economic and social consequences. For example, changes in the type of local vegetation, increasing water demand in agriculture, reducing agricultural production, increasing water consumption in urban areas, increasing energy consumption in the warm season and reducing the area of water bodies in the country are just some devastating consequences.

According to the results of this study, comprehensive planning at the national and regional levels as well as effective actions to reduce damage and increase adaptation and resilience seem necessary. It is also suggested that future climate change and the desertification process in the country be evaluated more carefully at the regional and local scales.

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