Climate change impact on spatial and temporal distribution of precipitation in Iran

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Abstract

Anticipated changes of precipitation as a result of climate change and global warming are very important in the assessment of climate change potential effects on various sectors such as water, agriculture, and surface water management. Precipitation has great complexities as the most important climatic element in Iran. The complexity is mostly due to the geographical location of vast land and has led to non-uniform spatial and temporal distribution of precipitation. this study aims is to evaluate the annual behavior of precipitation in Iran in the coming decades and precipitation statistical downscaling in Iran. In this regard, daily precipitation data of Iran 45 synoptic stations were prepared and downscaled in a period of 1981-2010 based on the LARS-WG model format to make identical data coordinate and scale with Atmospheric-Ocean General Circulation Model (AOGCM) data. Then, precipitation changes were analyzed for 2040-2070 and 2070-2099 decades in Iran based on emission scenarios (A2, A1B, and B1), and the HADCM3 model. The results of this study showed that simulated precipitation in Iran declined 11.5% based on the most optimistic scenario (B1) for a period of 2040-2070 and declined 14.2% based on the most pessimistic scenario (A2) for the base period. According to this scenario, Iran will not have reduced precipitation in the period of 1971- 2099 but it will have 0.8% increase in precipitation compared to baseline. Iran will have 9.6% decline in annual precipitation under the most pessimistic scenario (A2).

Keywords: Downscaling, Atmospheric-Ocean General Circulation Model, LARS-WG, Global Warming, Iran

1. INTRODUCTION

Climate change is one of the most important environmental challenges of the world; the consequences of climate change include rising temperatures, melting polar ices, rising global sea level, and climate threshold. The most important issue of today's world is competition for access to water resources. It is a problem that will lead most parts of the world, especially the Middle East into a new dimension of challenges. Reports are published recently worldwide that warn on water resources in the Middle East, including Iran.

Reports point to factors such as increased consumption, poor water resource management, droughts and especially climate change as factors that create critical conditions. Risks of climate change for these countries will be far beyond the water resources; this means that other areas such as health, environment, food security, and politic are threatened. Additionally, events that are occurred recently in climatology and water resources of Iran and their effects are presented by global warming, reduced precipitation, frequent droughts, and river runoff, show that decreased water resources and climate change must be accepted as a principle.

According to the most recent climate classification, about 90 percent of Iran has arid and semi-arid climate and more than 40 percent of Iran faces a severe water crisis (Masoodian, 2011). Therefore, in developing and vast countries like Iran where the shortage of water resources is a concern for economic and productive activities, changes in precipitation distribution have detrimental social and economic effects. On the other hand, precipitation in Iran is one of the essential factors to assess the water resources potentially; but its temporal and spatial distribution is quite uneven, that is why the water resources distribution is not uniform. The least spatial and temporal variability of precipitation, the more stable and homogeneous water resources will be and the constant supply of water resources will be possible (Masoodian, 2011). We intend to examine the effects and actions of climate changes on Iran's average annual precipitation through knowing the nature of climate changes and its effects and using tools such as models and climatic and emission scenario and with the knowledge of climate behavior in Iran.

We can use the outputs of Atmospheric General Circulation Models (GCM) to understand the effects of global warming and climate change in future periods. Since the spatial and temporal resolution of atmospheric general circulation models is low, so it is necessary to have tools and models for downscaling in order to convert the output of general circulation models into local variables on observation stations scale (Salon et al., 2008). It is common to use downscaling methods to model the climate behavior and its effects on precipitation all over the world and much research has been done in this field, including: (Zarghami et al., 2011; Babaeian et al., 2004; Busuioc et al., 2000; Dubrovsky et al., 2008; Tingem et al., 2008; Rajab, 2000).

In this study, the statistical model of LARS-WG is used in this research based on the study aim to downscale and reproduce data. The reliability and efficiency of this model are confirmed in studying the effects of climate change in various areas, including precipitation, temperature, and in many national and international studies. Some of these studies include (Hashemi ana, et al., 2015; Semenov et al., 2013; Khan et al., 2006; Chen et al., 2012; Fakhri et al., 2011; Ibrahim et al., 2014; Etemadi et al., 2014; Harmel et al., 2002; Gaitan et al., 2014; Zhang, 2003).

2. THE STUDY AREA

Iran is a vast country with an area of 1648195 square kilometers in South West Asia between latitudes of 25 and 40 degrees north and 44 to 63 degrees east in the Northern Hemisphere (Figure 1).

Figure 1. Iran's geographical position in south west Asia

Different climates dominate Iran due to the special geographical location and topographical characteristics of each region (Figure 2). According to the classifications of Masoodian (2011), Iran can be divided into eight climates (Figure 2).

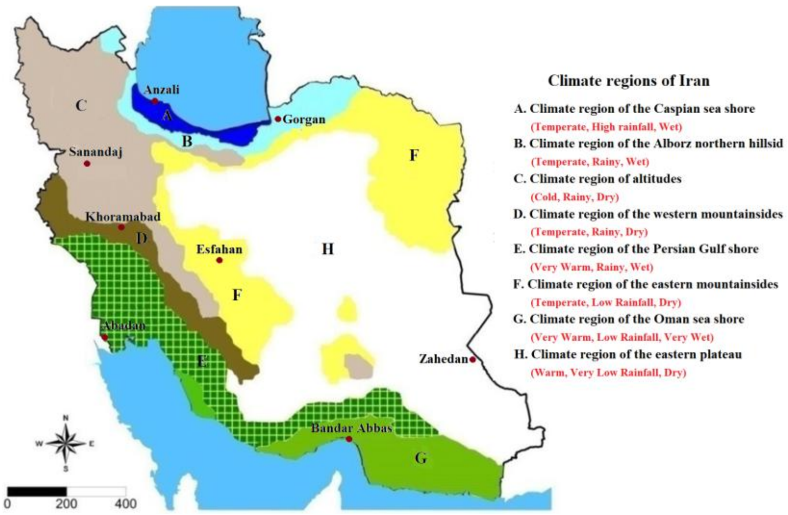


Figure 2. Iran's climatic classification

The mean annual precipitation of Iran is 250 mm where precipitation spatial distribution varies in different parts so that received precipitation of desert areas is less than 50 mm and annual precipitation of West Bank Caspian is nearly 1,800 mm (Figure 3).

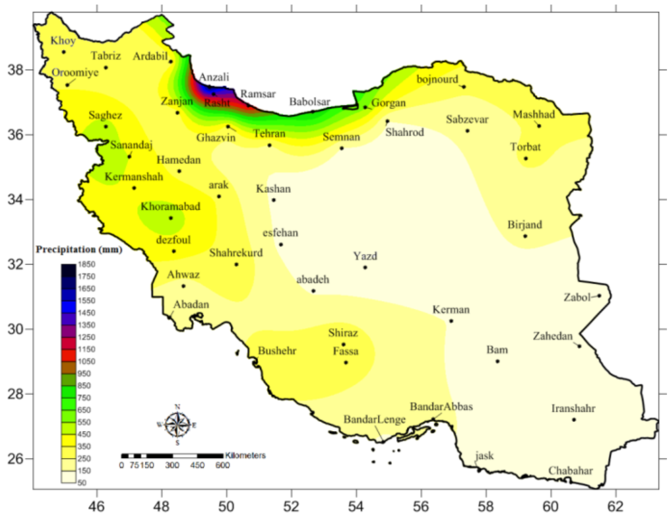


Figure 3. Spatial distribution of the mean annual precipitation of Iran for period of 1981-2010

3. DATA AND METHODOLOGY

According to this study that aims to examine the effects of climate change on Iran's annual precipitation, the necessary data were provided in two databases. The first database contained data on minimum temperature, maximum temperature, precipitation and sunshine hours per day for the period of 1981-2010 at 45 synoptic stations; stations name and geographical distribution are shown in Figure 3.Second base contained data that are downscaled by version 5 LARS-WG model and based on emission scenarios (B1, A1B, A2) of AOGCM models for two decades of 2041-2070 and 2071-2099. These data are related to the first database (minimum temperature, maximum temperature, precipitation, and sunshine) that are prepared based on model format and are used in order to analyze and predict climate change after downscale. The processing of these data is briefly described below.

Firstly, time series of observed data (precipitation, minimum temperature, maximum temperature and sunshine hours) of 45 synoptic stations were converted to proper format (LARS-WG5) for a basic statistical period of 1981-2010 after quality control. In the next step, all stations were calibrated in order to assess the performance of model (LARS-WG5) and to determine their statistical properties; then, the model was validated based on statistical indices (coefficient of determination (R2), Root mean square error (RMSE) and Willmott Index of Agreement (d) and model performance was confirmed in order to simulate the observed data. In the next step, the features of 15 Coupled Atmospheric-Ocean General Circulation Model were assessed under greenhouse gas emissions scenario that was embedded in the initial version of LARS-WG5 in order to downscale data based on (AOGCM) models; based on study aims a model was considered for final assessment that was valuable under three scenarios of B1-A1B - A2. A model was selected after validation and model performance and ability assessment in simulating extreme events (precipitation and temperature) was selected model that had the highest efficiency and lowest percentage of error. Finally Hadcm3 model was selected for simulation tools. Hadcm3 model characteristics and A2, A1B and B1 scenarios of this study are shown in Tables 2 and 3.

Table 1: Characteristics of the general circulation model of HadCM3 as the input of the software SDSM

GCM Model	IPCC	Scenario	Resolution	Reference
Hadcm3	IPCC4	A2, A1B, B2 SRES	2.5˚ × 3.75˚	AR4, Met Office, Hadley Center for Climate Prediction & Research (HCCPR), United Kingdom

Table 2. Summary of climatic scenarios characteristic of SRES in 2100 period (IPCC, 2007)

Emission Scenarios	World Population (Billion)	Gross Domestic Product (GDP) $10^{12}\$$	The Ratio of Per Capita Income	CO2 Density (ppm)	Global average temperature (℃)	Rising global in sea water level (cm)
1990	5.3	21	16.1	354	0	0
2000	6.1-6.2	25-28	12.3-14.2	367	0.2	2
2050						
A1B	8.7	181	2.8	536	1.6	17
A2	11.3	82	6.6	536	1.4	16
B1	8.7	136	3.6	491	1.2	15
2100						
A1B	7.1	529	1.6	711	2.9	39
A2	15.1	243	4.2	857	3.8	43
B1	7	328	1.8	538	2	31

4. DISCUSSION

In this research, Hadcm3 model output under emission scenarios of (A2, B1, A1B) that reflect optimistic, desirable and pessimistic concepts are used to determine the mean annual precipitation under climate changes. Analyzes were conducted for the near (2040-2070) and the far (2071-2099) climates. Figure 4 shows annual precipitation changes during the period of 2040-2070 under emission scenarios compared to the base period. As the maps show more stations of Iran have a decreasing trend of precipitation (brown) except a few stations that have increased trend of precipitation (blue). Most of annual precipitation decline changes are observed in West and North West of Iran. For more clarification, precipitation climate change scenarios are shown in Table 3 based on percentage of precipitation changes (increase or decrease) for all areas of Iran for two decades of 2050 and 2080 and under three pessimistic (A2), desirable (A1B) and optimistic (B1) scenarios. Accordingly, with regard to the most optimistic scenario (B1) for period of 2040-2070, Iran will have annual precipitation decline of 11.5 percent compared to base period. The highest percent of anticipated precipitation decline is related to Jask, Oroomyie, Kerman, Zabol and Tabriz stations. In contrast, Babolsar, Rasht, Mashhad, Qazvin, Ahwaz and Chabahar stations have increased precipitation of 1.4 to 25.9 percent (Table 3). Under the most pessimistic scenario (A2), Iran's central region will have 14.2% annual precipitation decline for the period of 2040- 2070 compared to baseline so that more areas of Iran will be exposed to precipitation decline and higher dry ratio. The provinces of West, North West, North East and large parts of Iran central and southern coasts will face with a steep decline in precipitation (Figure 4). At the same time, parts of North, South West and South East of Iran will face with a relative increase in precipitation. In general, the mean annual precipitation of entire country will be decreased as 12.5% during the period of 2040-2070 under all three scenarios.

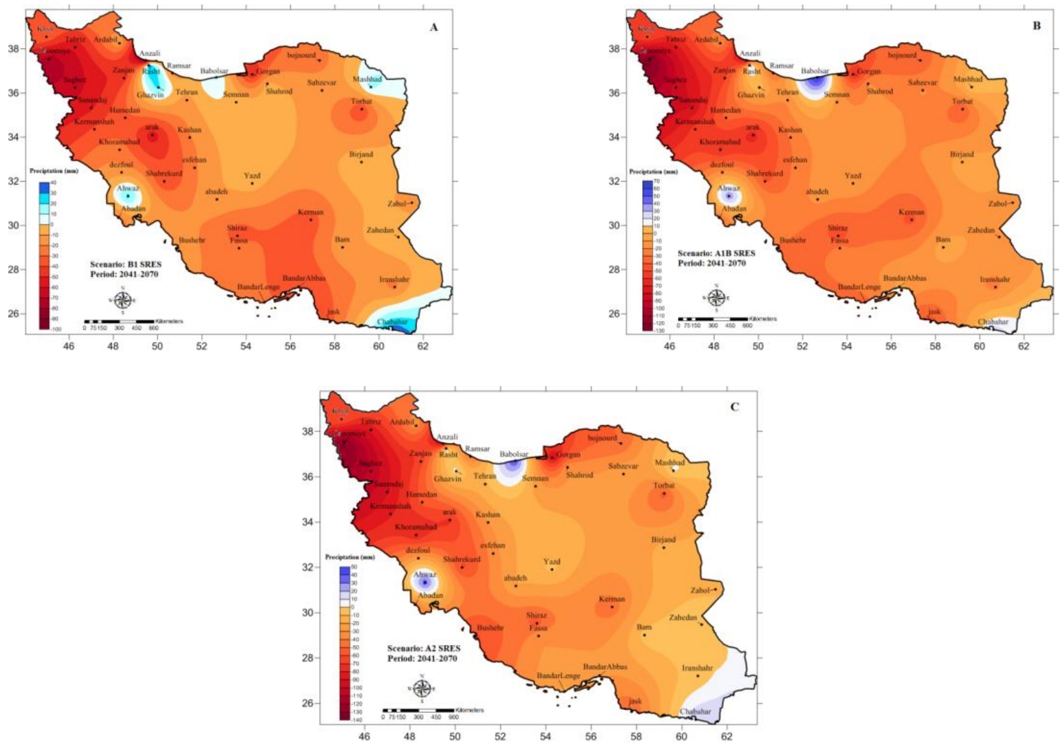
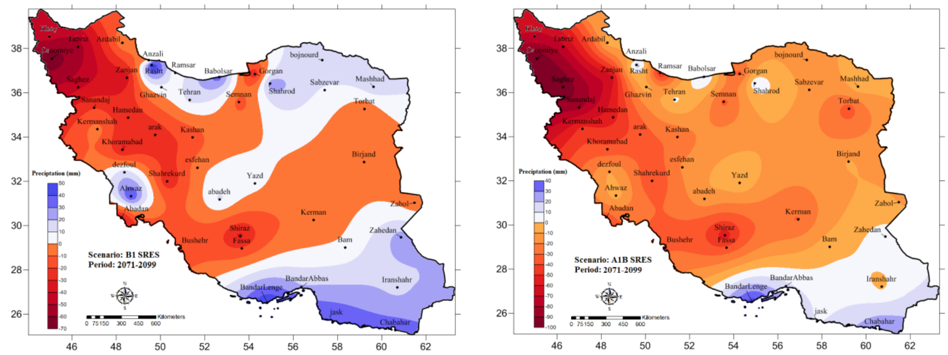


Figure 4. Spatial distribution of precipitation change amount for period of 2041-2070 compared to base period (198—2010) under climate change scenarios

Annual precipitation of Iran far climate (2071-2099) is different here from central region (2041-2070). Annual decline of Iran precipitation is reduced in this period and reaches half the previous period. According to the most optimistic scenario (B1), Iran will experience more humid conditions during this period (Figure 5a). According to the scenario Iran will have no decline in precipitation for the period of 1971-2099 but it will have an average of 0.8 percent increase in precipitation compared to the baseline (Table 3). South East, North East, South West and central parts of Iran will have an increasing trend in precipitation under this scenario and for the period of 2071- 2099. But West and North West of Iran will have declined trend of annual precipitation like previous period 2041-2070. Under the most pessimistic scenario (A2), Iran will have a decline of 9.6 percent in the amount of mean annual precipitation (Figure 3). According to this scenario, South East Iran Kerman including Zabol, Iranshahr, Bam, Bandar Lengeh, Bandar Abbas and Jask stations will have increased trend in annual precipitation and the rest of Iran will have reduction in annual precipitation. The maximum reduction in annual precipitation will be related to North West of Iran (Figure 5).



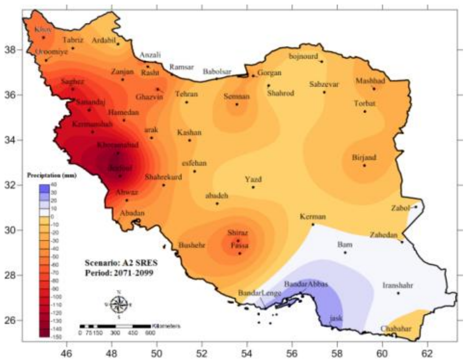


Figure 5. Spatial distribution of precipitation change amount for period of 2071-2099 compared to base period (198—2010) under climate change scenarios

Table 3. Change percentages in average annual precipitation of Iran during two periods (2041-2070 and 2071-2099) and according to A2, A1B and B2 scenarios

		A2 SRES scenario		A2 SRES scenario		A1B SRES scenario	
Station	Base Period	2041-2070	2071-2099	2041-2070	2071-2099	2041-2070	2071-2099
Abadan	159.1	-18.9	-22.1	-21.8	-23.9	-18.9	-18.9
Abadeh	137	-9.4	-8.7	8.9	-14.8	-12.2	-9.4
Ahwaz	209.2	10.0	-2.2	20.9	19.3	19.9	10.0
Anzali	1830.5	-5.6	-0.3	-0.3	-5.8	-5.2	-5.6
Arak	337.1	-20.8	-10.7	-8.1	-21.3	-19.3	-20.8
Ardabil	295.5	-4.1	-1.9	-0.6	-11.0	-7.0	-4.1
Babolsar	889.3	1.4	1.6	4.1	4.9	7.7	1.4
Bam	58.8	-21.3	-4.6	4.7	-10.1	-7.5	-21.3
BandarAbbas	176.1	-23.6	7.4	12.0	-16.3	-3.9	-23.6
BandarLenge	136.9	-25.8	33.3	37.4	-13.3	-24.2	-25.8
Birjand	168.5	-0.2	-5.4	-1.8	-9.8	-2.7	-0.2
Bojnourd	267.8	-11.0	-6.3	7.2	-18.5	-14.6	-11.0
Bushehr	268	-6.6	-11.7	-6.1	-23.5	-11.6	-6.6
Chabahar	118	25.9	26.4	30.0	17.0	20.6	25.9
Dezfoul	394.6	-4.0	-2.3	3.9	-6.0	-4.2	-4.0
Esfehan	125	-21.8	-14.7	-3.1	-27.8	-21.5	-21.8
Fassa	289.9	-8.2	-12.9	-6.5	-10.6	-8.7	-8.2
Ghazvin	314.4	7.1	-1.5	2.2	1.3	2.3	7.1
Gorgan	583.8	-10.0	-5.8	-4.9	-16.1	-11.2	-10.0
Hamedan	317.7	-11.2	-17.0	-8.1	-18.0	-11.7	-11.2
Iranshahr	111.9	-25.8	-1.9	14.6	-6.3	-20.9	-25.8
Jask	139.3	-35.9	6.3	29.4	-36.5	-33.4	-35.9
Kashan	136	-19.5	-20.8	-12.2	-21.7	-20.9	-19.5
Kerman	148	-34.0	-21.0	-5.6	-31.6	-29.6	-34.0
Kermanshah	439.2	-10.0	-10.3	-1.2	-18.4	-12.7	-10.0
Khoramabad	504.3	-5.3	-7.5	-6.3	-15.8	-12.2	-5.3
Khoy	289.2	-12.0	-25.1	-15.8	-18.7	-15.3	-12.0
Mashhad	251.5	5.3	-1.0	7.2	1.0	3.6	5.3
Oroomiye	342	-35.6	-28.6	-19.3	-38.9	-36.9	-35.6
Ramsar	1206.2	-1.4	-4.4	0.2	-3.9	-3.0	-1.4
Rasht	1337.5	2.8	1.6	4.2	0.5	2.1	2.8
Sabzevar	186.6	-8.3	-6.7	4.3	-11.2	-10.2	-8.3
Saghez	487.2	-15.9	-20.0	-8.6	-22.1	-17.7	-15.9
Sanandaj	449.9	-13.9	-18.6	-4.5	-20.2	-17.8	-13.9
Semnan	140.7	-2.1	-23.7	-10.3	-17.4	-10.2	-2.1
Shahrekurd	321.8	-14.4	-12.4	-8.7	-19.5	-13.1	-14.4
Shahrod	153.3	-5.1	5.4	17.1	-20.5	-12.2	-5.1

Shiraz	334.7	-13.2	-17.1	-10.0	-16.9	-14.7	-13.2
Tabriz	283.8	-27.7	-25.5	-19.3	-30.8	-26.0	-27.7
Tehran	232.7	-6.4	1.1	5.5	-5.4	-8.2	-6.4
Torbat	267.7	-17.4	-13.4	-3.3	-20.4	-14.9	-17.4
Yazd	59.2	-11.2	-2.4	5.2	-13.3	-19.0	-11.2
Zabol	57.7	-31.3	-17.8	-12.0	-20.2	-21.7	-31.3
Zahedan	89.3	-1.6	6.7	28.6	-3.5	-11.5	-1.6
Zanjan	311.1	-17.9	-20.9	-11.5	-21.3	-17.0	-17.9

5. Conclusion

This research evaluates the effects of climate change on mean annual precipitation of Iran under various scenarios and for coming decades 2040-2070 and 2071-2099. The reports of IPCC especially in their fourth and fifth report in Middle East region have predicted unfavorable conditions, particularly for Southwest Asia (Iran). A condition that is associated with decreased precipitation and increased temperature. The most important results of this study were as follows:

1. Performance indicators of HadCM3 models have the best performance and the lowest level simulation error in estimation of precipitation at all studied stations; the correlation between observed and simulated data is at a high level.
2. In this research, Hadcm3 model output under emission scenarios of (A2, B1, A1B) that reflect optimistic, desirable and pessimistic concepts are used in order to determine the mean annual precipitation under climate changes. Each of these analyzes was conducted for near (2040-2070) and far (2071-2099) climates.
3. Precipitation change scenario of periods 2040-2070 and 2071-2099 compared to base period under emissions scenarios showed that there is no coordination between precipitation models under various scenarios in coming period; decreased and increased precipitation is observed between 2040 and 2070 in most stations of country.
4. Precipitation change percentage of period 2071-2099 for all three scenarios and models showed less amounts than 2040-2070 decade. The reason for this may be partly due to the sensitivity of models in predicting climate changes.
5. According to the most optimistic scenario (B1), Iran's central region will have 11.5% annual precipitation decline for the period of 2040- 2070 compared to baseline. Under the most pessimistic scenario (A2), Iran's central region will have 14.2% annual precipitation decline for the period of 2040- 2070 compared to baseline so that more areas of Iran will be exposed to precipitation decline and higher dry ratio.
6. According to the most optimistic scenario (B1), Iran will experience more humid conditions during this period (Figure 5a). According to the scenario Iran will have no decline in precipitation for the period of 1971-2099 but it will have an average of 0.8 percent increase in precipitation compared to the baseline. Under the most pessimistic scenario (A2), Iran will have a decline of 9.6 percent in the amount of mean annual precipitation.

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