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ORIGINAL ARTICLE

Impact of climate change on water resources in Iran

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Abstract
Climate change may be defined as a change in the time variation of weather conditions over a period of time. It is caused due to amount of precipitation, temperature, rate of evaporation, and variation in solar radiation received by earth. Other than that, human activities have also been identified as significant causes of climate change and often referred to as global warming, and all regions of the world are expected to experience a net negative impact of climate change on water resources and freshwater ecosystems where, intensity and characteristics of the impact can vary significantly from region to region. It is worth mentioning that flash floods and drought are a worldwide hazard and it is necessary to address these complicated events. Therefore, there is an urgent need to understand the climate to provide adequate supplies of good-quality water for all people living today and future generations and sustain crucial functions of ecosystems. Several models have been used to predict climate change but long-term prediction of weather parameter is a challenge required for water resources management. For this reason, Fourier series and The Francou and Rodier empirical approach have been used for assessment of precipitation and flood analysis, respectively. It has been found that, the main effects of climate change related to water resources are rising temperature, shifts in precipitation patterns, snow cover, and increasing the likelihood of floods and droughts. Climate change may significantly change the seasonal variation in river flow changes too.

Keywords Climate change · Water resources · Precipitation · Temperature · Rate of evaporation

Introduction

Global water and temperature variation

The ocean holds 97% of the earth's water and the remaining 3% is freshwater found in glaciers and ice, below the ground, or in rivers and lakes. Although the absolute quantities of fresh water on earth have always remained approximately the same, the uneven distribution of water and population growth continues to create growing problems of fresh water availability and accessibility.

Water scarcity occurs when the amount of water withdrawn from lakes, rivers or groundwater is so great that water supplies are no longer adequate to satisfy all human or ecosystem requirements, resulting in increased competition between water users and other demands. The overall goal is to ensure that adequate supplies of good-quality water will be available to all people, those who live today and future generations, by maintaining the quantity and quality of water needed to sustain the vital ecosystem's performance. Extensive infrastructure for water resources control, including dams and reservoirs, as well as large systems for inter-basin water transfer, have contributed significantly to the effective management of water resources. However, these projects themselves have given rise to a variety of new environmental problems such as a loss of biodiversity through landscape alteration, disruption of critical fish migration routes between downstream floodplains and upstream tributaries, salinization of soils in regions around reservoirs due to rising groundwater levels, and finally, through saline water invasion in estuary regions due to a decline in discharges from the impoundment of freshwater in reservoirs. Therefore, water is going to quickly become a limiting factor in

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our lifetimes (http://www.ipcc.ch/ipccreports/ar4-wg1.htm), hence, important foci for further research include climate change impacts on water resources, flood, and drought forecasting and prevention, and environmental assessment of water resources development projects.

Several models such as U.S. Standard Atmosphere (USSA), Goddard Institute for Space Studies (GISS), National Center for Atmospheric Research (NCAR), and Geophysical Fluid Dynamics Laboratory (GFDL) have been developed by Academy of Science of the United states, Canada, United Kingdom, Australia and Russia to predict climate change. These models are based on meteorological information to determine temperature and carbon dioxide variation as in Fig. 1 (https://www.ncdc.noaa.gov/sotc/global/201613). It may be seen that temperature shows a slight cooling trend while CO_2 has been rising steadily. However, it is to be noted that in a long-term warming trend, there are short periods of cooling at the temperature record over the past several decades. According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on earth has increased by about 0.8 °C (1.4° Fahrenheit) since 1880. Two-thirds of the warming has occurred since 1975, at a rate of roughly 0.15–0.20 °C per decade.

Water resources in Iran

General

The geographical location of Iran is in such a way that three different climatic conditions can be identified in its various regions (Iran Meteorological Organization 2014). The humid type prevalent in the coastal area of the Caspian Sea with mean annual rainfall of 1600 mm. The semi-arid type

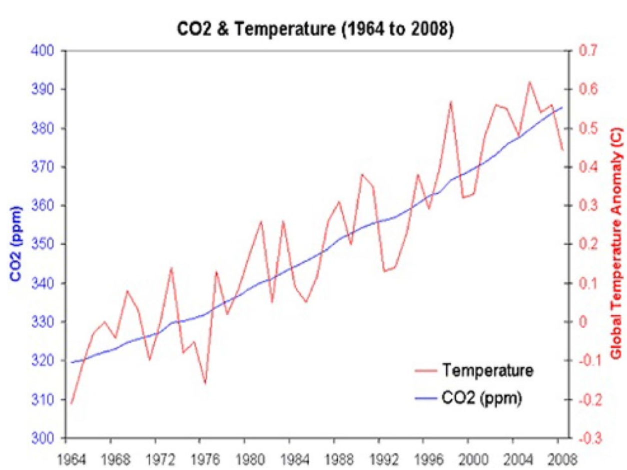

Fig. 1 Atmospheric CO_2 (parts per million, NOAA) and global temperature anomaly (°C GISS)

encountered in the mountainous regions of Zagross, with mean annual rainfall of 450 mm and, the arid type of the deserted expanses of the country with mean annual rainfall of 50 mm. Annual rainfall of the Caspian coast in northern Iran, has brought wet forests and woodlands and deserted regions of the country have a minimal annual precipitation. Of the average annual rainfall volume of 413 billion cubic meter (bcm), an estimated 71% evaporates before reaching the rivers. The total long-term annual renewable water resources are estimated at 130 bcm, of which about 80 bcm go to surface runoff and groundwater recharge is estimated at about 50 bcm per annum. The average annual precipitation is estimated at 250 mm, varying from 50 mm in parts of the central water basin, to more than 1100 mm in some coastal areas near the Caspian Sea (Rostam Afshar 1996). The global average annual precipitation is more than 830 mm, classifying Iran as arid and semi-arid country.

Rainfall analysis

It may be noted that extreme precipitation and flash floods become more common as a result of climate change. They are closely tied and are known as a worldwide hazard. It is therefore important to monitor and evaluate how climate has changed in the past to enable the protection of people and critical infrastructure. Table 1 shows average monthly rainfall (mm) for 28 years' data and temperature variation. It may be seen that June is the hottest month with a temperature of 35.9 °C and the coldest is January at 2.8 °C. Throughout the year, temperature varies by 33.1 °C. The wettest month is February with an average of 43 mm of rain. In July, rainfall is at its lowest, with an average of 2.8 mm. the difference in precipitation is

Table 1 Average monthly rainfall (mm) for 28 years' data and temperature variation

Month	Average rainfall (mm)	Actual rainfall (mm)	Mean temperature (°C)
Oct.	7.9	7.6	18
Nov.	19	10.7	11
Dec.	34.17	10.4	5.4
Jan.	39.8	27.1	2.8
Feb.	43	19.8	5.1
Mar.	40.5	–	9.5
Apr.	34.3	–	15.1
May.	22.7	–	21.2
Jun.	6.2	–	35.9
Jul.	2.8	–	29.3
Aug.	3.3	–	28.6
Sep.	4.6	–	24.4
Total	258.3	75.6	–

Table 2 Average monthly rainfall (mm) for 28 years' data and simulated outputs for 300 years

Status	Total		Percentage	
	5 months	12 months	5 months	12 months
Simulated outputs				
28 years average precipitation	143.87	258.3	100%	100%
Maximum rainfall	209.2	375.3	145.4	145.29
Mean rainfall	143.5	257.8	99.74	99.8
Minimum rainfall	62.5	112	43.44	43.36
Actual rainfall	75.6	–	52.54	–

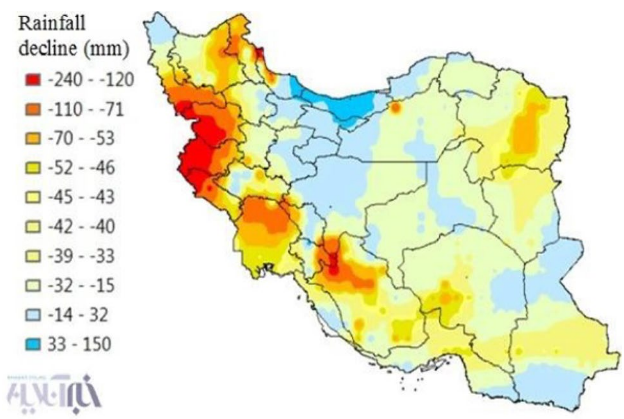

Fig. 2 Average rainfall variation (mm) from 1977 to 2012

40.2 mm between the driest and wettest months. Recent study (Rostam Afshar and Fahmi 2012) reveals the ability of Fourier Series to simulate long-term rainfall up to 300 years is viewed as an important finding in the study of rainfall forecast. Analysis of average monthly rainfall (mm) for 28 years' data with simulation outputs, given in Table 2 indicates that annual rainfall of the country would follow the trend of minimum rainfall obtained from simulated outputs which is 43.36% of the long-term historical time series. Furthermore, there is a shift of 1 month in the distribution of rainfall for long rainy seasons. It has also been found that rainfall in most parts of the country especially the western parts, has been decreased during the survey period from 1977 to 2012 as shown in Fig. 2 (https://www.khabaronline.ir), where negative values indicate a decrease in rainfall.

Impact of surface temperature

According to https://www.khabaronline.ir, Fig. 3a shows that temperature has been increased by 1.1 °C from 1977 to 2012. Furthermore, it has been found that temperature may increase by 2–3 °C in most parts of the Alborz region by 2050 as given in Fig. 3b. It may be noted that, an increase in surface temperature triggering changes in evaporation, precipitation, surface, and underground water and thereby quantity and quality of water resources will be more critical.

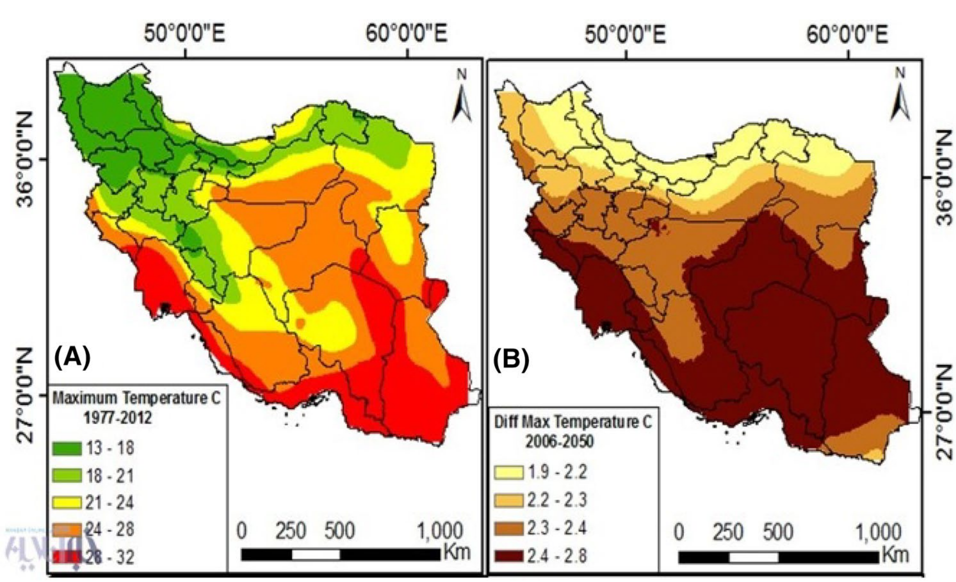

Fig. 3 Average maximum temperature from 1977–2012 and prediction of temperature until 2050

Assessment of evaporation

It is important to investigate potential changes in temperature, precipitation, solar radiation, and evaporation for assessing impact of climate change on water resources. As air temperature increases, more water evaporate*s* into the air. Warmer air can hold more water vapor, which can lead to more intense rainstorms, causing major problems like extreme flooding. The rate of evaporation is about 2000 mm which is about 3 times the global average. In the analysis of evaporation data, it was noticed that out of 600 evaporation stations, 54% of the stations have been affected by climate change as there has been an increment of temperature by 1.1 °C from 1977 to 2012. It has been found that temperature may increase by 2–3 °C in most parts of the Alborz region by 2050. If there is an increment of temperature by 2 °C and the total precipitation throughout the country (413 bcm) kept constant, the potential evaporation will increase by 6.7%, which comes to be 26.00 bcm and equivalent to capacity of existing reservoirs.

Table 3 Flood index based on the Francou–Rodier theory

No.	Location	Francou–Rodier index (*K*)	Flood severity
1	Khuzestan	4.5–4.8	Critical
2	Sistan and Baluchestan	4.4–4.6	High
3	Gilan	4.3–4.5	High
4	Fars	4.2–4.4	Medium
5	Kerman	4.2–4.3	Medium
6	Khorasan	4.0–4.2	Medium
7	Azarbayejan	3.8–4.1	Low
8	Mazandaran	3.8–4.0	Low

Flood assessment

The Francou–Rodier approach (1967) was used to assess the flood severity and is given in Table 3. It may be seen that significant variation was observed in Francou–Rodier Index which indicates increasing river flood in 54% of total hydrometry stations under investigation. Furthermore, analysis of flood occurrence reveals that number of devastating floods has been increased even though average annual rainfall remained unchanged which might be due to climate change. Analysis of data indicates that the annual runoff will undergo significant changes with more runoff in winter and less in spring by shifting parts of the spring melt runoff to an earlier peak in winter which may be due to climate change phenomena. According to https://www.khabaronline.ir, Fig. 4 shows the flood in Ilam and Lorestan provinces in the western part of Iran, in August 13th, 2008, which caused at least nine deaths. The results show that this flood trend will be extending and exacerbating the flooding.

Caspian sea level

The Caspian Sea is surrounded by five countries: Russia, Kazakhstan, Turkmenistan, Iran, and Azerbaijan. Four tide gauge stations from which the historical Caspian Sea level observation time series is derived. Analysis of the Caspian Sea level indicates that both the rise during the years 1926–1975 (about 3 m) and fall during 1975–1995 (about 2 m) may be due to influence in the process of its intrusion as a result of climate change as in Fig. 5 (Khoshraftar 2006). Jianli (2017) shows water levels in the Caspian Sea dropped nearly 7 cm per year from 1996 to 2015, or nearly 1.5 meters total. The current Caspian Sea level is only about 1 m above the historic low level (−28.5 m) reached in the late 1970s.

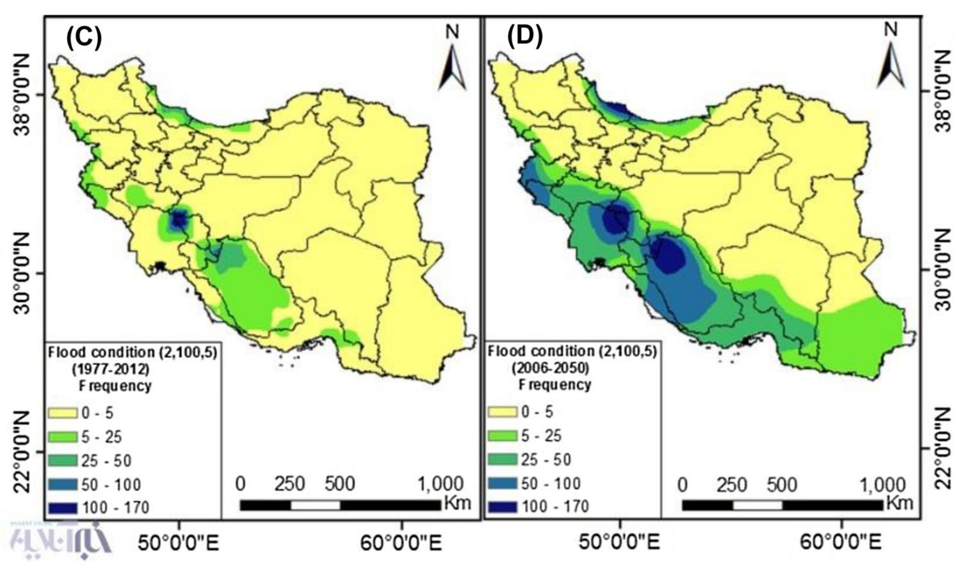

Fig. 4 Flood in Ilam and Lorestan provinces in August 13th, 2008

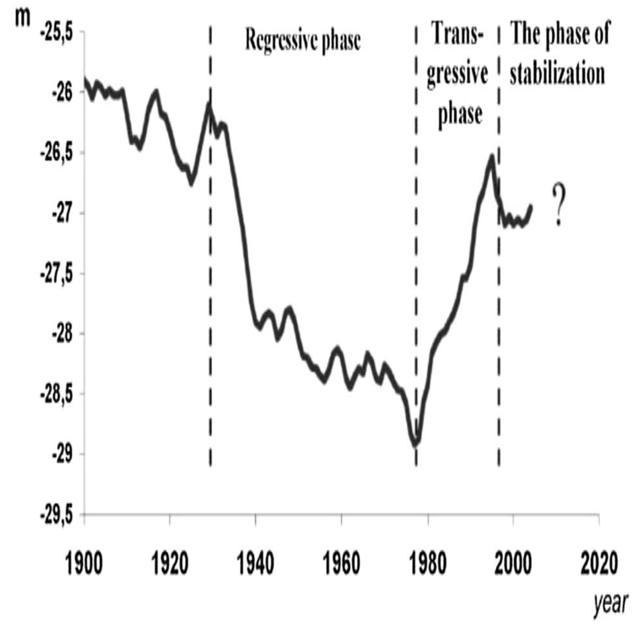

Fig. 5 Caspian Sea level during 1900–2020

Increased evaporation over the Caspian Sea has been linked to increased surface air temperatures. The average yearly surface temperature over the Caspian Sea rose by about 1 °C between the two timeframes studied, 1979–1995 and 1996–2015. These rising temperatures are probably a result of climate change. Evaporation brought about by warming temperatures appears to be the primary cause of the current drop in sea level, and the decline will probably continue as the planet warms.

Conclusion

The main effects of climate change related to water resources are rising temperatures, shifts in precipitation patterns, snow cover, and increasing the likelihood of floods and droughts. Climate change may significantly change the seasonal variation in river-flow changes. Higher temperatures will push the snow line upwards in mountainous regions which reduces precipitation and causes a higher winter runoff. Moreover, earlier spring melts will lead to a shift in peak flow levels. As a result of the declining snow cover and decreasing glaciers, there will be less water to compensate for the low flow rates in summer. Listed below are the summary of the results:

1. Annual rainfall of the country would follow the trend of minimum rainfall obtained from simulated outputs which is 43.36% of the long-term historical time series (dry period which may last from 5 to 8 years). Furthermore, there is a shift of 1 month in the distribution of rainfall for long rainy seasons and analysis of data indicates snow melting process at least 1 month earlier.
2. There has been an increment of temperature by 1.1 °C from 1977 to 2012. Furthermore, it has been found that temperature may increase by 2–3 °C in most parts of the Alborz region by 2050.
3. It has been found that temperature may increase by 2–3 °C in most parts of the Alborz region by 2050. If there is an increment of temperature by 2 °C and the total precipitation throughout the country (413 bcm) kept constant, the potential evaporation will increase by 6.7%, which comes to be 26.00 bcm and equivalent to capacity of existing reservoirs.
4. Analysis of data indicates that the annual runoff has undergone significant changes with more runoff in winter and less in spring by shifting parts of the spring-melt runoff to an earlier peak in winter which may be due to climate change phenomena.
5. Caspian Sea level has been dropped nearly by 1.5 meters. The current Caspian Sea level is only about 1 m above the historic low level (− 28.50 m) reached in the late 1970s.

Recommendation

Climate change is a big challenge for the country and requires action at a large scale by the government. There are many things that can be done to reduce energy consumption and promote smart energy choices.

1. To step up use of clean energy like wind, wave, tidal, and solar energy.
2. To increase the energy efficiency of buildings, factories, and cars.
3. To redesign transport system by improving and increasing the use of public transport.
4. To set up energy production more efficiently.
5. To set up low carbon economy with minimal use of fossil fuels.

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