

Chapter 1

Standing Up to Climate Change: Creating Prospects for a Sustainable Future in Rural Iran



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1.1 Introduction

Climate change is the mega topic of the twenty-first century and usually described as any change in climate over time, it is due to natural changes or human activities (IPCC 2014; World Bank 2017; Lange 2019). This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines the term climate change as a change of climate, directly or indirectly attributed to human actions that changes the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods (NCCO 2017; IPCC 2018). Climate change is certainly accelerated by the increase in greenhouse gas concentrations, which originates mainly from the combustion of fossil fuels. Global warming as the main effect of climate change has led to rising sea levels, changes in storm patterns, altered ocean currents, changes in rainfall, the melting of glaciers, more extreme heat events, fires, and drought. The Intergovernmental Panel on Climate

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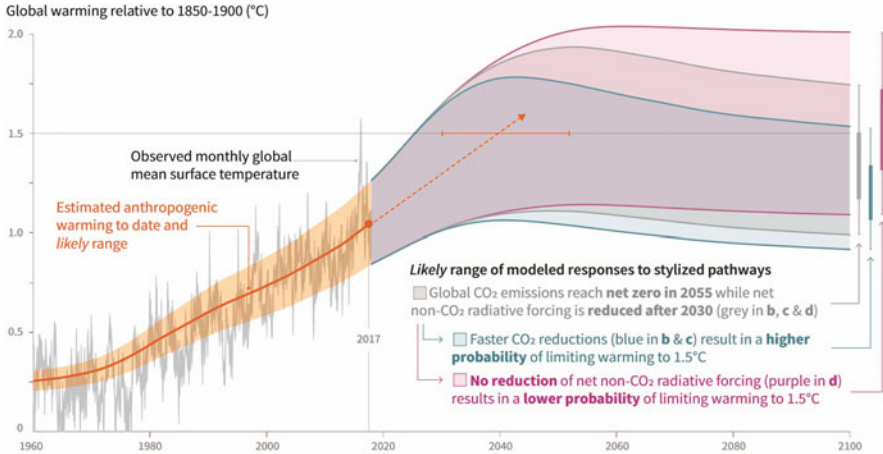


Fig. 1.1 Observed monthly global mean surface temperature (GMST, gray line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) change and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed likely range) (source: IPCC 2018) [Orange dashed arrow and horizontal orange error bar show respectively the central estimate and likely range of the time at which 1.5 °C is reached if the current rate of warming continues. The gray plume to the right of panel shows the likely range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO₂ emissions decline in a straight line from 2020 to reach net zero in 2055 and net non-CO₂ radiative forcing increases to 2030 and then declines. The blue plume in panel shows the response to faster CO₂ emissions reductions, reaching net zero in 2040, reducing cumulative CO₂ emissions. The purple plume shows the response to net CO₂ emissions declining to zero in 2055, with net non-CO₂ forcing remaining constant after 2030. The vertical error bars on the right of panel show the likely ranges (thin lines) and central terciles (33–66 percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways (data from the Global Carbon Project) (source: IPCC 2018)]

Change (IPCC) has identified and characterized scientifically global causes and impacts of climate change since 1990. Their latest report again highlights exacerbated land degradation, desertification, expansion of arid climate zones, intensified dust storms and threats to food security, human health, and economic activities as dramatic impacts of climatic change particularly in arid and semiarid regions (IPCC 2019).

For three years in a row now, the World Economic Forum Global Risk Report identifies climate change and related environmental impacts as the standout long-term risks the world faces (World Economic Forum 2019). According to the Fifth Assessment Report of IPCC (AR5), the warming of the climate system is unequivocal (see also Fig. 1.1 taken from the Summary for Policymakers). With regard to particular changes in frequency and intensity of precipitation, numerous studies indicate that global warming is leading to a deterioration of the ecosystem and development of a water crisis (Falkenmark and Rockström 2006; Zuo et al. 2015). This process exacerbates water scarcity, particularly in dry and semidry regions and intensifies spatial and temporal variabilities of water resources on basin level (Milly et al. 2005; Vörösmarty et al. 2010; Dastorani and Poormohammadi 2016). Murphy

and Ellis (2017) point out the particular vulnerability of watersheds by showing that watershed climate is more sensitive to climate change than other areas. In addition, Huang et al. (2016) show that global semiarid regions have grown enormously over a 60-year scope. Many sectors suffer from direct or indirect effects on the economy due to the high variation and decline in rainfall in dry and semidry areas, which again leads to a loss of livelihoods (Anyamba et al. 2014) and, most likely, affects surface water variation (Chiew et al. 2009).

Mitigating climate change would require substantial and sustained reductions in greenhouse gas (GHG) emissions. Strategies for mitigation and adaptation to climate change need to be underpinned by common enabling factors like effective institutions and governance, adequate funding, innovation, and investments in environmentally sound technologies and a revision of the build infrastructure. It is therefore vital for all countries, especially those in arid and semiarid regions, to take mitigation and adaptation measures simultaneously.

1.2 Climate Change Perspectives in the MENA Region

The adverse effects of climate change affect all countries. Countries in the Middle East and North Africa (MENA) region (Fig. 1.2) are particularly vulnerable to persistent droughts, rising sea levels, threatening food security, water and energy supplies, and health (see an overview of developments and challenges resulting from climate change in the MENA region by Ribbe and Denavi in this volume; Verner 2012; Wodon et al. 2014; Göll 2017; Waha et al. 2017; World Bank 2017). MENA is the most water scarce region in the world. According to a recent World Bank report, over 60% of the MENA region's population lives in areas with high or very high



Fig. 1.2 The Middle East and North Africa (MENA) region (Source: World Bank 2017)

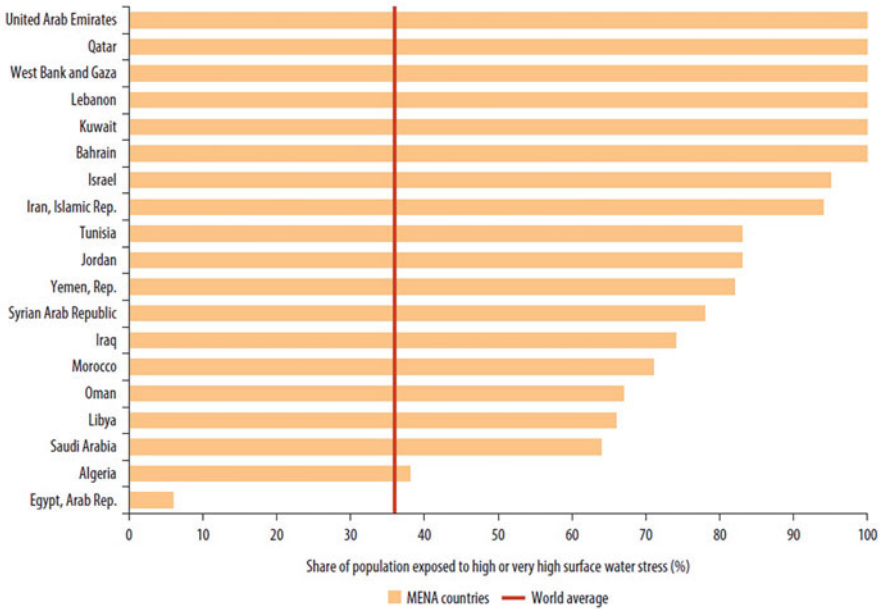


Fig. 1.3 Population (%) exposed to high or very high surface water stress, by country and economy, 2010 (Source: World Bank 2017) [Areas where water withdrawals are 40% or more of surface water supplies are considered to have high or very high stress. Caution should be used in comparing data on annual freshwater withdrawals, which are subject to variations in collection and estimation methods. In addition, inflows and outflows are estimated at different times and different levels of quality and precision, requiring caution in interpreting the data. This calculation does not account for water stress arising from upstream developments that may cause shortages in downstream countries and economies (World Bank 2017).]

surface water stress with reduced available amounts of water for immediate uses such as agriculture or filling reservoirs for drinking water (World Bank 2017) (Fig. 1.3). Over 70% of the region's gross domestic product (GDP) is generated in areas with high to very high surface water stress (World Bank 2017). The region would be severely affected by a global warming of 2 °C and even more of 4 °C, particularly because of the increase in projected heat extremes, the consequent reduction in water availability and the expected negative consequences for regional food security (Fig. 1.4) (World Bank 2014).

Due to the changing precipitation patterns, water insecurity and projected sea level rise, the region will face major challenges, particularly in the areas of agriculture, water, and food security (Göll 2017). These biophysical effects, coupled with other pressures and a lack of resilience in some countries in the region, will likely cause high vulnerabilities in these sectors and for social dimensions (Waha et al. 2017).

The MENA region is water scarce, and most of the land area receives less than 300 mm of annual rainfall (200–300 mm is the lower limit for rain-fed agriculture).

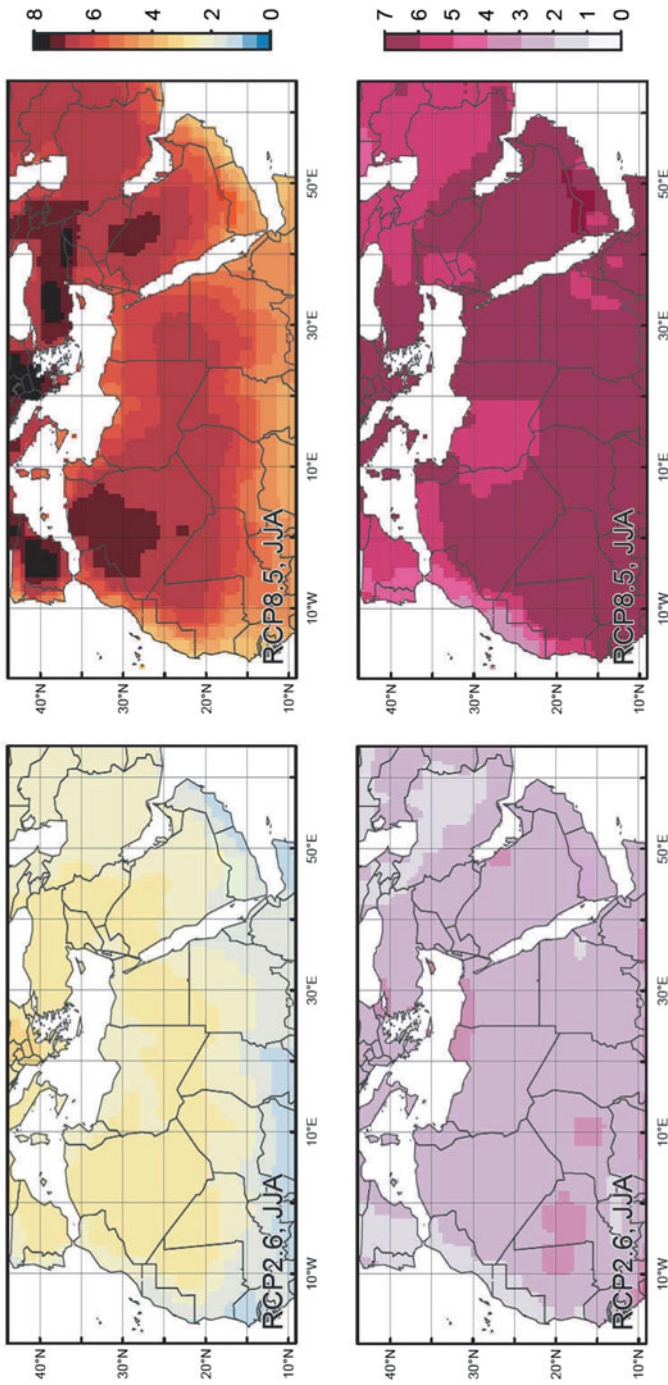


Fig. 1.4 Multi-model mean temperature anomaly for RCP2.6 (2 °C world, left) and RCP8.5 (4 °C world, right) for the Middle East and North African region [Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–2099 relative to 1951–1980 and normalized by the local standard deviation (bottom row) (World Bank 2014)]

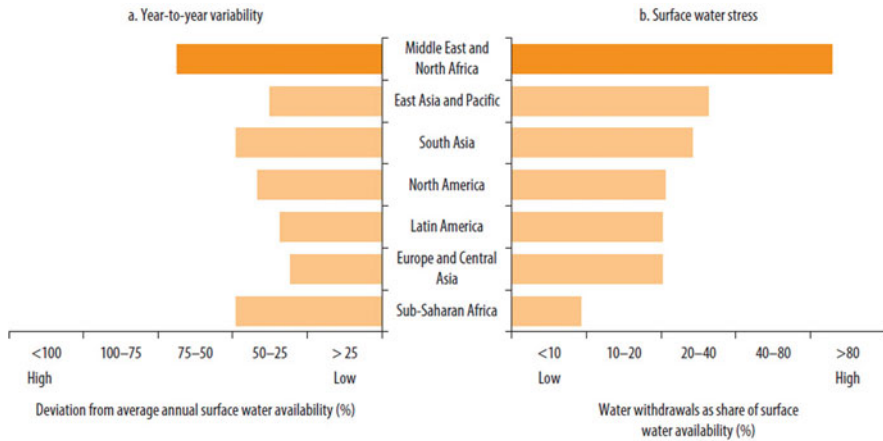


Fig. 1.5 Water stress and year-to-year variability in surface water, by world region (World Bank 2017) [Water stress measures total water withdrawals as a percentage of total surface water availability. It does not account for dependence on transboundary water sources or nonconventional water sources. Year-to-year variability measures the percent deviation from mean annual surface water availability. (World Bank 2017)]

The annual availability of renewable water resources is below 1000 m^3 per capita in most countries (World Bank 2014). Given the current situation of water scarcity and a lack of arable land, climate change would put further pressure on water resources, agriculture, and food security (World Bank 2014, 2017; Göll 2017; Waha et al. 2017; Lange 2019). In addition, the strong variability from year-to-year in the region is prone to multi-year droughts and intense rainfall events, which can lead to destructive flooding (Fig. 1.5).

The agricultural sector, of which 70% is entirely rainfed, is also exposed to strongly changing climatic conditions (Waha et al. 2017). A warmer and drier climate is expected to shift the vegetation and agricultural zones to the north, and lower rainfall and higher temperatures will presumably shorten wheat growing periods in large parts of the region by about 2 weeks by the middle of the century (2031–2050) (World Bank 2014). It is expected that crop yields in parts of the MENA region will decrease by 30–60% without taking adaptation into account. Reductions in crop productivity are expected by mid-century. Legumes and maize crops are expected to be worst affected as they are grown during the summer (World Bank 2014). Climate change will affect animal production in a number of ways, including changes in the quantity and quality of available feeds, changes in the length of the grazing season, additional heat stress, reduced drinking water, and changes in livestock diseases and disease vectors (World Bank 2014). This is crucial as the agriculture sector is the largest employer in many MENA countries and makes a significant contribution to the national economy. Increasing food and water demands pose even greater risks to the region's prosperity, as the population is expected to double by 2070 (Waha et al. 2017).

Natural climate variability and global warming can influence precipitation patterns around the world, contributing to desertification. On the one hand, a decrease in precipitation means that soils dry out and become more susceptible to erosion (Smith et al. 2017). Furthermore, heavy rainfall itself may erode soil and cause waterlogging and ground subsidence. The MENA region is largely threatened by dust storms that threatens people's health, agriculture, and the economy.

With additional pressure on already scarce resources and the intensification of existing threats such as political instability, poverty, and unemployment, climate change could act as a threat multiplier in the region. This can create the conditions for social uprising and violent conflict. The MENA region is already characterized by very high summer temperatures, making the region's populations highly susceptible to further temperature increases. The deterioration in livelihoods in rural areas can contribute to internal and international migration and further burden urban infrastructure and the associated health risks for poor migrants. Migration and climate-related pressure on resources might increase the risk of conflict (World Bank 2014). Establishing a direct link between climate change and conflicts is challenging due to several factors and conflicting conclusions and methods. Further research is needed to investigate and determine the relationship between climate change and conflict and to relate long-term climate change to migration and social conflicts.

1.3 Climate Changes Perspectives in Iran

Iran is a typical example of a MENA region that is particularly affected by climate change. About 52% of the country consists of mountains and deserts and 16% are higher than 2000 m above sea level. More than half of Iran's land consists of mountains, with a quarter being plains and deserts and less than a quarter being arable land (FAO 2008). As depicted in Fig. 1.6, Iran lies in a belt of regions with

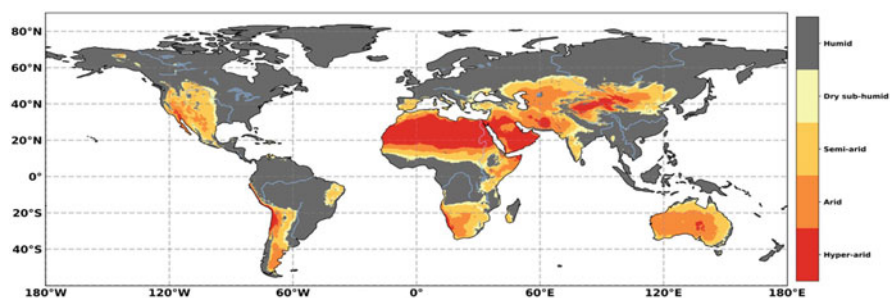


Fig. 1.6 Geographical distribution of drylands delimited based on the aridity index (AI) (Mirzabaev et al. 2019) [The classification of AI is: Humid $AI > 0.65$, Dry sub-humid $0.50 < AI \leq 0.65$, Semiarid $0.20 < AI \leq 0.50$, Arid $0.05 < AI \leq 0.20$, Hyper-arid $AI < 0.05$. Data: Terra Climate precipitation and potential evapotranspiration (1980–2015)]

arid and hyper-arid conditions. Apart from the coastal areas, the temperature in Iran varies between 22 °C and 26 °C, and the average annual precipitation is around 240 mm. Total precipitation provides 417 BCM of water, of which 300 BCM (72%) evaporate. In addition to the 117 BCM of available water, 13 BCM flows into the country from neighboring countries through rivers, making 130 BCM of water available (Iran's Third National Communication to UNFCCC, NCCO 2017).

Iran has recently taken more decisive measures to adapt to and mitigate climate change, based on Article 50 of its Constitution, to insure legal protection of the environment. Forward to international cooperation: Iran presented Initial and Second National Communications to the UNFCCC in 2003 and 2011, respectively. In this ongoing process, the Third National Communication (TNC) to UNFCCC also fulfills the country's commitment as a Non-Annex I Party to the Convention, to prepare and present the Convention with updated reports on national GHG emission inventory,¹ national GHG mitigation policies, vulnerability, and adaptation, national strategies, a Global Climate Observation System (GCOS), research and education and economic assessments (NCCO 2017). Iran's National Climate Change Office (NCCO), among other tasks (including raising public awareness and national coordination of the Sub-committee for Sustainable Development), has built national capacities to systematically address climate change through measures such as providing Iran's Low-carbon Economy Document, Intended National Determined Contribution (INDC), and the National Strategic Plan on Climate Change. All these measures necessitated a considerable amount of duly recognized effort in providing these inputs (NCCO 2017).

A recent study on long-term changes in maximum, minimum, and average temperature and changes of precipitation in the country reveal that Iran will experience an average temperature rise of 2.6 °C and rainfall decrease of 35% over the next few decades (Daneshvar et al. 2019). Both temperature and precipitation variabilities can influence rainfall patterns, water resources, and agricultural activities, which can lead to droughts and floods and thus desertification and dust storms (Vaghefi et al. 2019).

1.3.1 The Water–Food–Health Nexus

Based on the literature review, the main impacts of climate change on Iran's water resources are rising temperatures, changes in rainfall patterns, less snow cover and an increased likelihood of floods and droughts (Abbaspour et al. 2009; Hashemi 2015; Afshar and Fahmi 2019; Vaghefi et al. 2019). Madani (2014) highlights water crises in Iran, including depleting groundwater levels, the drying out of lakes, the water supply, and extreme weather events. In connection with administrative problems, Iran has faced many disasters, including a significant number of shrinking

¹As of 2014, Iran was the seventh largest CO₂ emitter with 649,481 Kilotons CO₂/year.

lakes and dry rivers that had led to land subsidence, floods,² and droughts. Lake Urmia—the largest lake in the Middle East and one of the largest hypersaline lakes in the world—has shrunk considerably and may completely dry up in 6 to 9 years (Vaghefi et al. 2019). Hamun Lake in eastern Iran, Parishan and Shadegan lakes in the south, and Zayandeh Rud river in central Iran are also at risk of disappearing due to mismanagement and climate change. The study by Abbaspour et al. (2009) stated that groundwater recharge in regions with already scarce water resources will decrease by up to 50–100% in the eastern part of the country. Future analyses of extreme dry periods in Iran show a significant 16-fold increase in most of the country, south of the Alborz Mountain chain (Fig. 1.7).

The World Bank (2017) report also indicates an increased surface water stress due to climate change in countries like Iran, which are in a politically and ecologically fragile situation (see Fig. 1.8). The Blue Water Sustainability Index created by The World Bank (2017) for the MENA region expresses that most of Iran's water consumption is covered by unsustainable extraction (see Fig. 1.9). The results of a study by Besalatpour et al. on blue water and green water resources changes in a basin in central Iran (Zayandeh Rud river basin) are presented in Chap. 6. The authors' findings show that the green water flow component in the eastern part of the catchment is relatively increased due to the influence of climate changes in the past. Their results indicate that, in general, the amounts of blue water and green water storage were greater in the western part of the study area than the eastern parts. The authors' findings provide valuable information about the spatial (in sub-basin scale) and temporal (annual and monthly) distribution of water resources which can be useful for long-term planning and optimal management of the study area.

Based on the report from Iran's Third National Communication to UNFCCC, published by the NCCO, the impacts of climate change on Iran's water resources for the period 2015–2030 compared to the period 1982–2009 can be summarized as follows (NCCO 2017):

- The evaporation volume of the country increased by 27.3 BCM due to the increase of two degrees in temperature.
- Recharge of the groundwater decreased by 20%, due to the increase of two degrees in temperature.
- Snowfall reduced by 5% and snowmelt time shift by 1 month. Also, the snow level increased to 200 meters. This trend will continue in the future.
- The likelihood of severe droughts and severe floods will increase in the future.
- Precipitation trends that are less than 5 mm and 10 mm will continue to decrease.
- According to the pessimistic scenarios, runoff changes are decreasing in all basins.

²From 2015 to 2018, approximately six major floods occurred in unexpected regions located in arid and semiarid parts of Iran. In addition, floods in the northern edge of the country often cause substantial damage. The worst flooding disaster occurred in August 2001, where a once in 200-year-flood affected more than 27,000 people, rendered 10,000 homeless, and killed about 250 people in Golestan Province in northern Iran (Vaghefi et al. 2019).

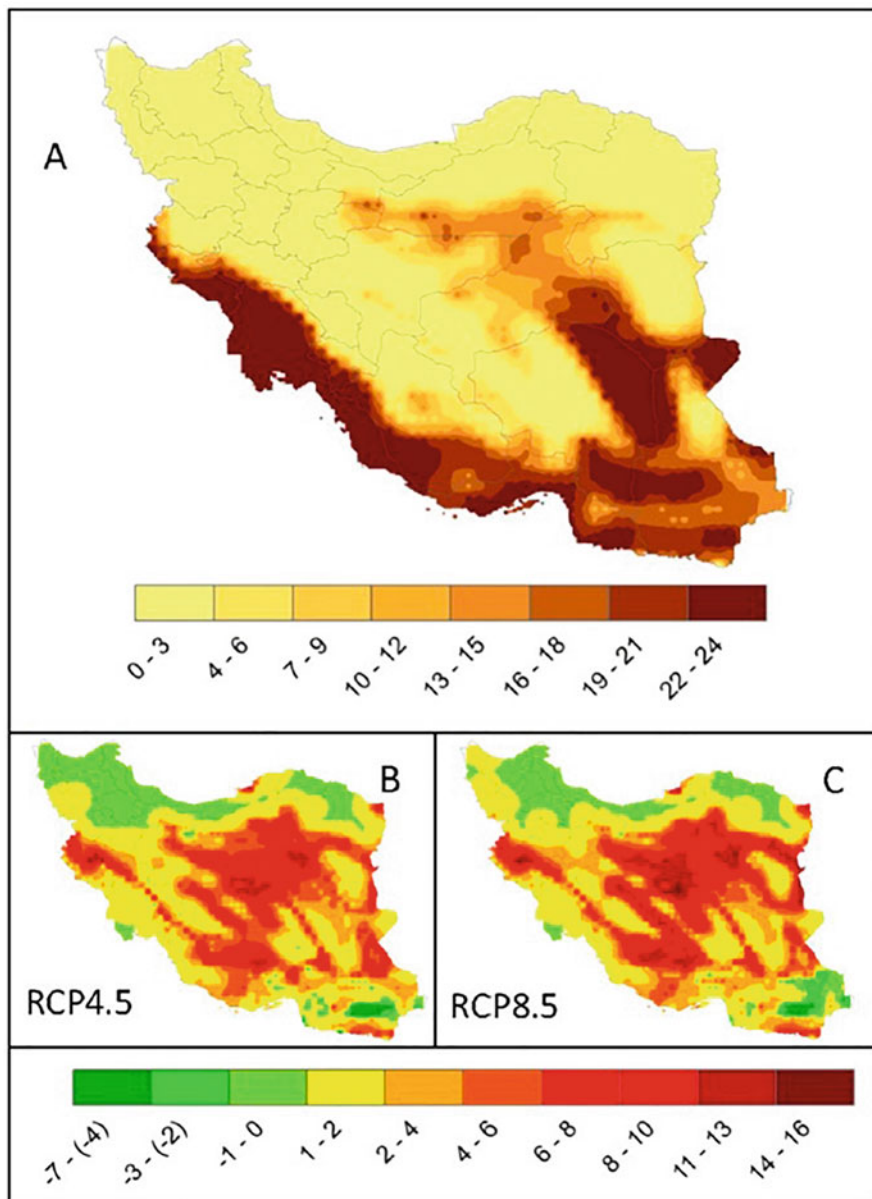


Fig. 1.7 Compound analysis for dry periods where (for ≥ 120 consecutive days, rainfall < 2 mm day $^{-1}$ and $T_{max} \geq 30^{\circ}\text{C}$) (Vaghefi et al. 2019) [(A) shows the frequency of such conditions in the past (1980–2004). (B, C) Illustrate the difference between the historical and the future (2025–2049) frequencies of the events. Increasing extreme dry periods are predicted for hot dry desert and hot semi-desert areas, while the Caspian Sea’s mild and wet zone may experience fewer extreme dry conditions in both scenarios]

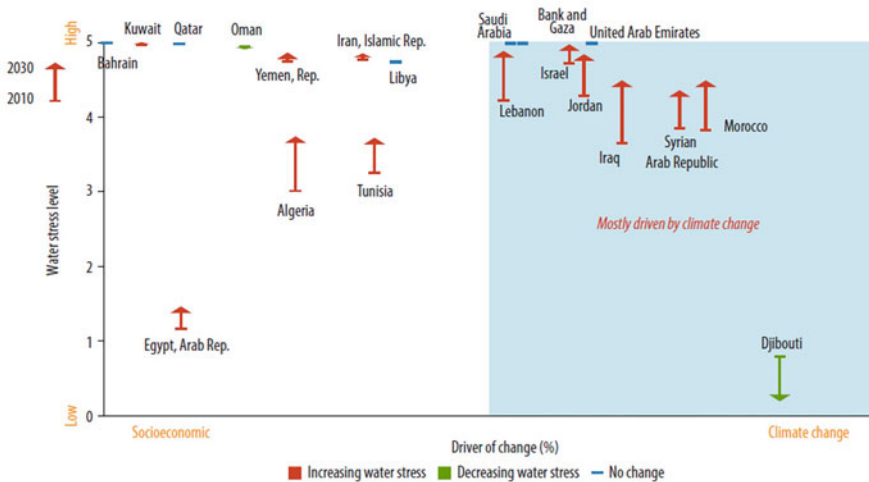


Fig. 1.8 Future drivers of surface water stress in the Middle East and North Africa (World Bank, 2017) [Water stress is quantified as the ratio of annual water withdrawals to average annual surface water availability under an RCP 8.5 (high emission scenario) and SSP2 (business as usual for a socioeconomic change). The position of each country along the horizontal dimension reflects the percent change in water stress, which is driven by climate change (right) or socioeconomic change (left). Future climate change is modeled using an ensemble of climate models for a high emission scenario (RCP 8.5). Socioeconomic change is modeled using a middle-of-the-road scenario where future socioeconomic trajectories do not shift markedly from historical patterns (that is, a business-as-usual scenario for population growth and the economy). Estimates of surface water stress do not account for withdrawals from groundwater and nonconventional water supplies (World Bank 2017)]

- Unsafe drinking water supply in most major cities in the future.
- Warmer and more humid conditions increase the spread of diseases in the tropical regions.

In order to be able to feed a growing population of currently 82 million Iranians, scarce water resources must be managed effectively. Given the dynamic of land degradation and desertification facilitated by climate change, it is evident that sustainable management mechanisms must be used to avoid persistent land degradation. In this regard, spatial planning and integrated management of water resources; promoting the productivity and a comprehensive approach to managing water resources; improve efficiency and sustainability in the use of shared water resources in close cooperation with neighboring countries; consideration of the economic, security, political, and environmental values of water in order to achieve a desirable use, supply, maintenance, and consumption need to be considered (NCCO 2017).

In Iran, the agricultural sector accounts for about 18% of GDP. Previous studies show that Iran’s total crop yield is expected to decrease in all climate change scenarios. However, the extent of the changes in yield depends on the type of

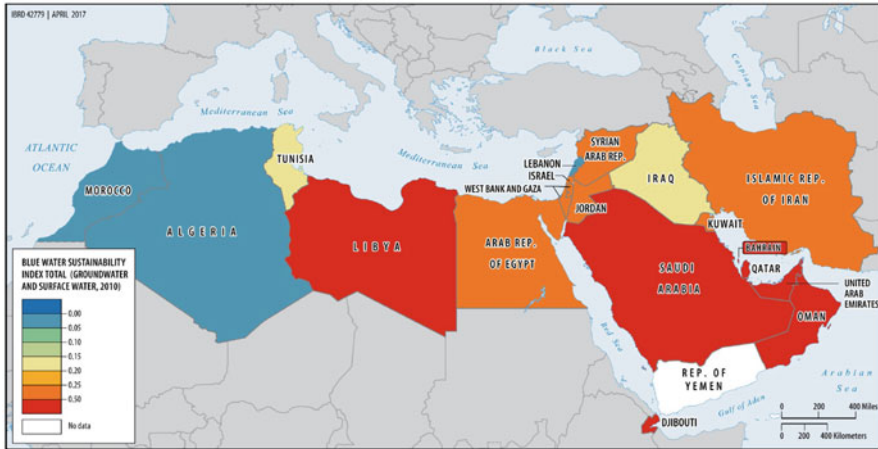


Fig. 1.9 Blue Water Sustainability Index, Middle East and North Africa, 2010 (World Bank 2017) [The BIWSI is a dimensionless quantity ranging from 0 to 1 that expresses the portion of consumptive water use that is met from non-sustainable water sources. Blue = sustainable; red = unsustainable. Non-sustainable surface water use is estimated as the amount of environmental flow requirements not satisfied due to surface water over-abstraction. Non-sustainable groundwater use is estimated as the difference between groundwater abstraction and natural groundwater recharge plus recharge from irrigation return flows (World Bank 2017)]

crop, the assumptions regarding the CO₂ fertilization effect, the climate scenarios, and the possibilities for adaptation (Karimi et al., 2018). The rise in mean yearly temperature, especially in winter, could also extend the growing season. The NCCO (2017) report shows that the net irrigation needs of irrigated wheat and alfalfa will increase, while it will decrease for irrigated forage corn in most parts of the country during the period 2016–2030. The potential yields of irrigated wheat, alfalfa, and forage corn will also decrease in most parts of the country over the same period (NCCO 2017). Salemi et al. (Chap. 15 of this volume) calculate the water demands of autumn and spring plants using the example of the eastern region of the Zayandeh Rud river basin in central Iran. They show how the optimization of computer algorithms and the establishment of a sound database of net water requirements and related maps can support decision-makers in developing sustainable agricultural sector strategies.

The Communication to the UNFCCC (NCCO 2017) presents various possible solutions to effectively deal with these important consequences of climate change, ranging from sustainable soil and water management to socioeconomic policies for reducing poverty in rural areas. Involving farmers in the conservation of water and soil resources and combating the effects of climate change is crucial.

1.3.2 Desertification, Salinization, and Dust Storms

Climate variability and anthropogenic climate change, both leading to an increase in air temperature on the land surface and evapotranspiration and a decrease in precipitation, have played a role in desertification in Iran in interaction with human activities such as overuse of water (Emadodin et al. 2019). Desertification and climate change are expected to reduce the productivity of crop and livestock, change the composition of plant species, and reduce biological diversity in dry and semi-dry areas (Mirzabaev et al. 2019; Emadodin et al. 2019). It is reported that around one million km² of land is at risk of desertification (Jafari and Bakhshandehmehr 2013; Emadodin et al. 2019). In Chap. 3 of this volume, Amiraslani, and Caiserman shed light on current water management policies in Iran. Several initiatives have been implemented to tackle water shortages in the country, nonetheless, these measures have not been sufficient to address the environmental challenges of the dimensions that exist in Iran. The relevant question remains what kind of strategies of the national level can tackle land degradation and water shortage simultaneously? Using a literature review and employing reliable data and statistics, Amiraslani and Caiserman portray the contemporary situation of water resources in Iran and provide initial answers to the pivotal questions raised.

Climate change as manifested by drought and desertification has led to a substantial increase in dust generation in many arid and semiarid countries as well as in Iran (Moulin et al. 1997; Ekanem and Nwagbara 2005; Middleton 2019). Dust storm frequencies and intensities have increased significantly in recent years (see Fig. 1.10) and have had a huge influence on the economy and environment of Iran and thus on the daily life of Iranian people. At least five million people are directly affected by dust storms, and many more are indirectly influenced by the transfer of sand particles into their habitats (Morabbi 2011; Cao et al. 2015). It should be noted that dust storm sediments in the region are high in salinity and a number of socioeconomic impacts have been identified, including threats to human health (Middleton 2019). Aghasi et al., in Chap. 10 of this volume, assess the origin of annual dusts produced in the Zayandeh Rud River basin in Central Iran and the effects of dry sediments of the Gavkhuni wetland on the regional environment.

1.4 Perspectives on Climate Change in the Zayandeh Rud River Basin

The Zayandeh Rud in Central Iran is one of the country's most important rivers, providing water for more than four million inhabitants. Originating in the Zāgros Mountains at an altitude of about 2300 m, the river passes vast agricultural areas, large scale industry sites and the city of Isfahan, before it ends after about 350 km in the Gavkhuni wetland at an altitude of 1500 m, an area listed by the Ramsar Convention as protected wetlands in 1975 (Fig. 1.11). The basin with an area of

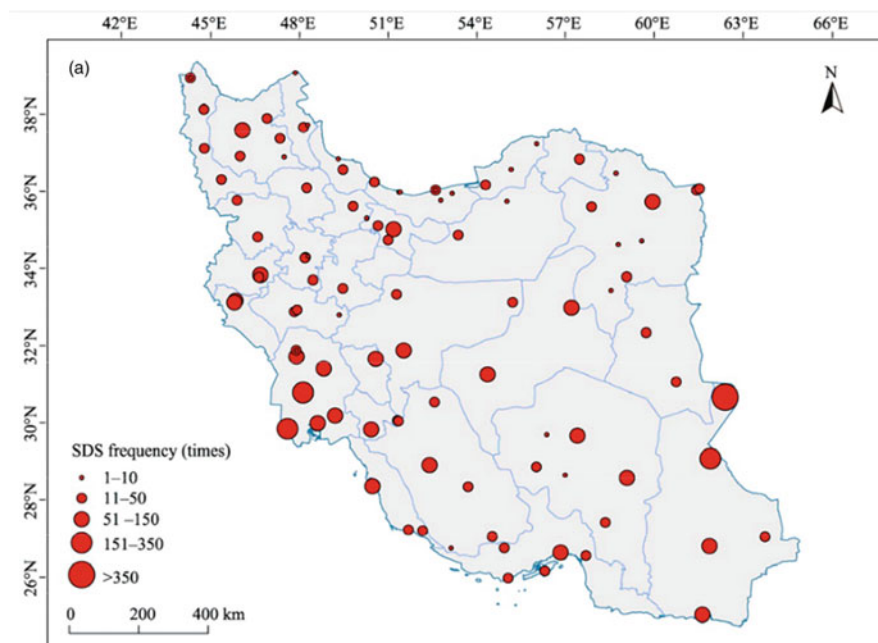


Fig. 1.10 Sand and dust storms frequency map in Iran from 2000–2013 (Source: Cao et al. 2015)

about 27,000 km² is located mainly in the Province of Isfahan. It has a predominantly arid or semiarid desert climate with annual precipitation as low as 55 mm in the east, whereas the mountainous western part may be considered as semi-humid with an average annual rainfall of 1500 mm. Rainfall in the basin averages to 265 mm per year with a wet season in winter. Temperatures have always been high in summer at an average of 30 °C and as low as 3 °C during winter (Mohajeri et al. 2016; Mohajeri and Horlemann 2017). Annual potential evapotranspiration makes irrigation necessary for agricultural activities in the main part of the basin (Molle et al. 2004).

The exceptional geostrategic location of the Zayandeh Rud basin has been the driving force for socioeconomic, cultural, and political growth around the city of Isfahan, the former capital of Iran. It has been a hub, not only for culture and trade, but for regional water resources management with interbasin water transfers into the basin, and from the basin to other regions. During the past 60 years, the Zayandeh Rud Basin has enjoyed a flourishing population growth from one to almost four million inhabitants particularly in urban areas. Furthermore, a thriving industry employs more than 300,000 people, and agricultural areas expand up to 225,000 ha, situated mainly in six large irrigation schemes consuming up to 90% of the water in the basin (Mohajeri et al. 2016; Raber 2017).

These developments, and with them the boost of water users, have led to an increasing water demand in the basin. Between 2000 and 2010 2 BCM of water has

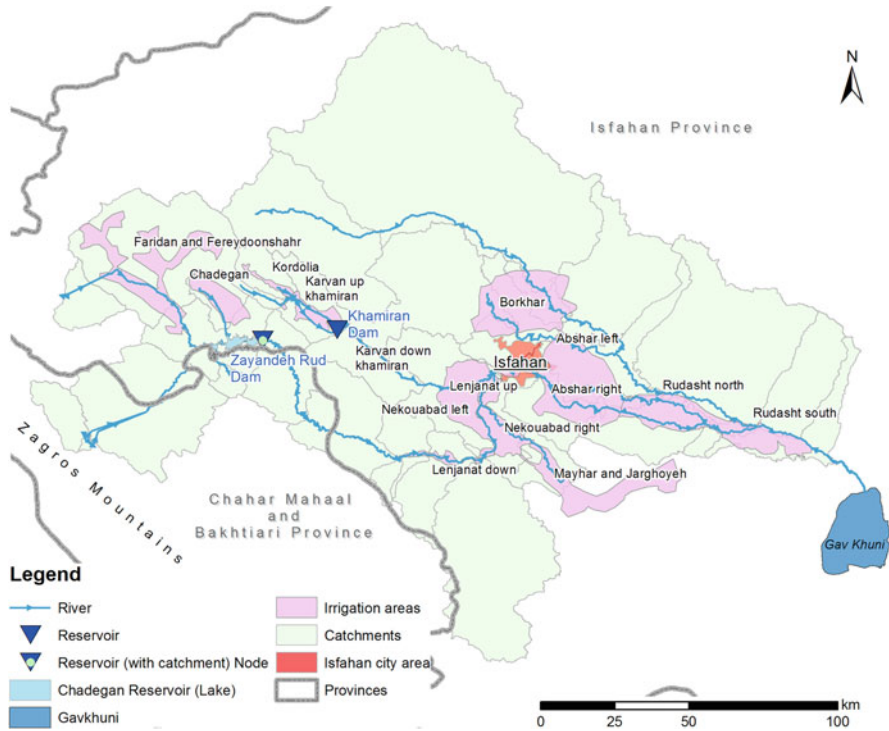


Fig. 1.11 Zayandeh Rud Catchment (Source: Mohajeri et al., 2017)

been used annually in the catchment including water transfers to neighboring provinces, whereas only 533–1720 MCM could be provided by the main Zayandeh Rud reservoir (Torfe et al. 2017). Water distribution patterns are determined by the distribution of legal water entitlements, challenging the historic water distribution rationales. Ziaei (Chap. 4 of this volume) elaborates on how the traditional way of distributing water between farmers is organized—according to the Sheikh Baha’I Scroll that has evolved over the centuries, but is no longer suitable to coping with today’s water problems. He shows how the excessive distribution of water entitlements in the past have contributed to today’s water crisis and consequential social unrest.

The responses to the deficit in water supply have mostly been technocratic in nature, altering the natural hydrology of the region by extracting more water from other basins. Groundwater resources are intensively exploited, upstream users have taken advantage of their privileged access to water resources and water is being redistributed to urban and industrial users (Molle and Mamanpoush 2012). The rural downstream irrigation networks and the environment in the basin have been the losers of the harsh competition for scarce water resources in the closed basin (Molle et al. 2009). In the lower reaches of the Zayandeh Rud River, most people live from agriculture. In years with sufficient water resources, the local irrigation networks

provide water for around 70,000 ha of cultivated area. Together with the Gavkhuni wetland, the Roodasht irrigation network is surrounded by desert and highly affected by climate change impacts (Eslamian et al. 2017). Torfe et al. (2017) indicate that the Gavkhuni wetland has received less than 30 MCM annually between 2000 and 2010, when its natural minimum water requirement is calculated in different studies to be between 70 and 240 MCM. Iranmehr et al. (2015) have analyzed remote sensing data for a 10-year period between 2003 and 2013 and show that more than 40% of the Gavkhuni wetland and Zayandeh Rud ecosystem have declined.

Raber et al. (Chap. 7) present an overview of the complex dynamics of water availability, land-use change, and environmental degradation using the example of the Roodasht region. A vulnerability analysis of farmers towards water scarcity induced by climatic and socioeconomic changes were carried out. The chapter presents its findings with a particular focus on water availability and management in terms of physical appearance, legal aspects, and actual decision-making in the eastern part of the Zayandeh Rud basin. Furthermore, the complex impacts of water management practiced during the past decades on agriculture, water, and soil quality, as well as on ecosystems like the Gavkhuni wetland are analyzed.

The overexploitation of water resources driven by the ideal of socioeconomic growth and everlasting control over natural resources has been and will further be amplified by impacts of climate change in the region, characterized by global warming, less precipitation, higher climate variability, and land degradation (IPCC 2019). Publications that present results from different climatic models all forecast that annual temperature is going to increase by around 1 °C in the basin (Kouhestani et al. 2017) and particularly in the eastern part (Gohari et al. 2013, 2017; Zareian et al. 2016; Eslamian et al. 2017). In Fig. 1.12 Eslamian et al. (2017) present temperature projections for the Zayandeh Rud basin by analyzing 15 Global Climate Models under the A2 and B1 emission scenario of the 2007 IPCC Report. Regarding the projections, they expect a dramatic temperature increase in the arid eastern part of the basin of one to two degrees.

At the same time, researchers forecast that precipitation is going to decrease in the western part of the basin where the Zayandeh Rud has its main source of water (Gohari et al. 2013, 2017; Zareian et al. 2016; Eslamian et al. 2017). Precipitation projections across the whole basin do not indicate a general trend. As presented in Fig. 1.13, the western mountainous part of the basin has a general decreasing trend particularly in winter and springtime. Only the A2 scenario with 25% probability percentiles does not confirm this overall trend. By contrast, precipitation projections for the eastern part of the basin do not show this general decreasing trend, but in this arid part of the basin, annual average precipitation is anyhow as low as 55 mm (Gohari et al. 2017).

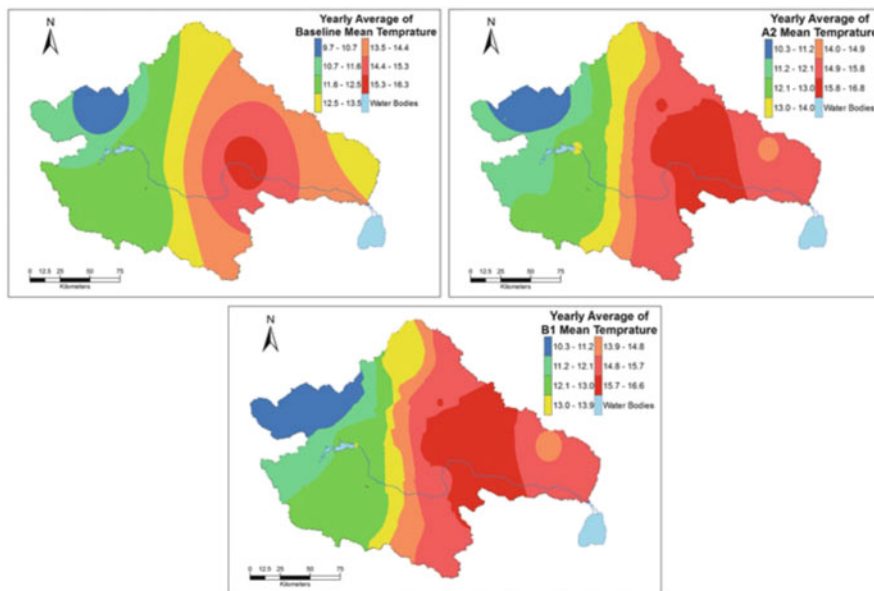


Fig. 1.12 The Zayandeh Rud Basin’s annual mean temperature under baseline period (1971–2000) and A2 and B1 climate change scenarios (2015–2044) (Source: Eslamian et al. 2017)

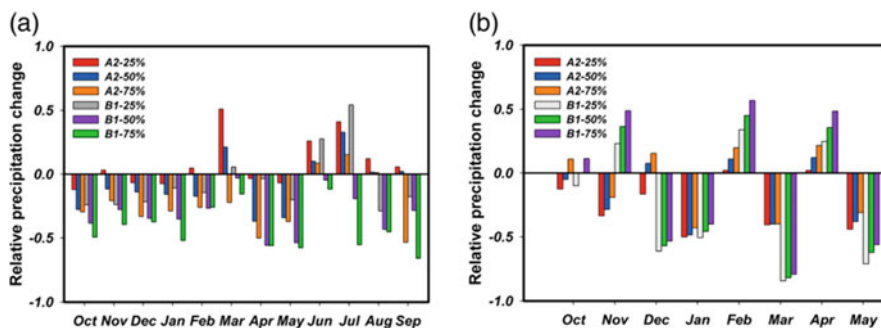


Fig. 1.13 Projected monthly precipitation changes under different climate change scenarios (2015–2044) relative to the baseline period (1971–2000) for: (a) the western part of the basin; and (b) the eastern part of the basin (June, July, August, and September are not shown due to minimal baseline precipitation levels in the lower sub-basin) (Source: Gohari et al. 2017)

1.4.1 Consequences of Climate Change in the Zayandeh Rud Basin

Climate change-induced drought can cause severe damage to vulnerable ecosystems. Therefore, understanding the implications of climate change on drought is important for water resources management. Naeini et al. (Chap. 5) discuss drought indices

calculated for drought duration, severity, and peak intensity in the east Zayandeh Rud Basin for a historical period (1979–2008), the present and the near future (2016–2057), and the distant future (2058–2099) using 15 general circulation models (GCM) from the IPCC Fifth Assessment Report (AR5) scenarios. A significant past drought event in the basin was used as a benchmark with specific severity, duration, and peak intensity. Results from the historical analysis suggest that the return period of significant drought is expected to increase in the future. Also, in some of the GCM's results, drought conditions in the western part of the basin were more severe compared to the eastern part. The characteristics of the projected altered climatic regime in the catchment have severe impacts particularly on agriculture. While warming may potentially shorten the growth period of certain crops, the crop productions of all crops are expected to decrease due to lower precipitation and higher water requirements, resulting from higher temperature (Gohari et al. 2013). Under the A2 emission scenario potential evapotranspiration, a factor for the water demand of crops, would increase by 3.1–4.8% in the basin (Zareian et al. 2016).

Wheat, barley, rice, and corn are popular crops in the basin and account for roughly 55% of the total cultivated area (reference year 2006) (Raber 2017). Gohari et al. (2013) show that these crops have a negative response in terms of yield on the projected climate scenarios for the period between 2015 and 2044. A dry and warm future will reduce wheat production, depending on the climate scenario, by 2.5–20.7%, barley by 1.4–17.2%, rice by 2.1–9.5% and corn by 5.7–19.1%. They argue that, on the one hand, higher temperature causes shorter growing periods resulting in yield loss, and on the other hand, heat increases irrigation water demand. Under most climate change scenarios, these two factors result in a decrease in water productivity as a key figure for the amount of physical production of a crop per unit volume of water used (see Fig. 1.14) (Gohari et al. 2013).

Rising temperatures and scarce water resources lead to another major risk for agriculture: In the basin where each drop of water is used several times along its passage through the river, pollutants, and salts accumulate in the water. Saline water is used for irrigation and due to low applied volumes and high temperatures, water is being evaporated and transpired by plants, salts accumulate in the top layer of the soil, making land unsuitable for agriculture and prone to degradation and desertification. Only 5% of the total land of Isfahan Province is considered arable but shows high soil salinity and low soil organic matter. Particularly the lower part of the Zayandeh Rud is affected by soil salinization and alkalinity (Fathi and Rezaei 2013). Salinity levels of water used for irrigation in Zayandeh Rud vary substantially from EC values of less than 1 dS/m in the upper reaches up to around 6 dS/m with peaks of 19.6 dS/m in the lower reaches (Pourmoghaddas 2006). In Roodasht, soil salinity is reported to be about 14 dS/m with negative impacts on crop yields as field experiments in the area have shown (Salemi et al. 2000).

Remote sensing analysis for a 10-year period between 2003 and 2013 revealed that salt-affected areas have expanded in the basin to more than 90% (Iranmehr et al. 2015). Establishing landscape evolution studies helps to improve the understanding of physical environments in soil-related studies. The objective of Toomanian and Salemi's work presented in Chap. 8 is to depict the historic evolution of the

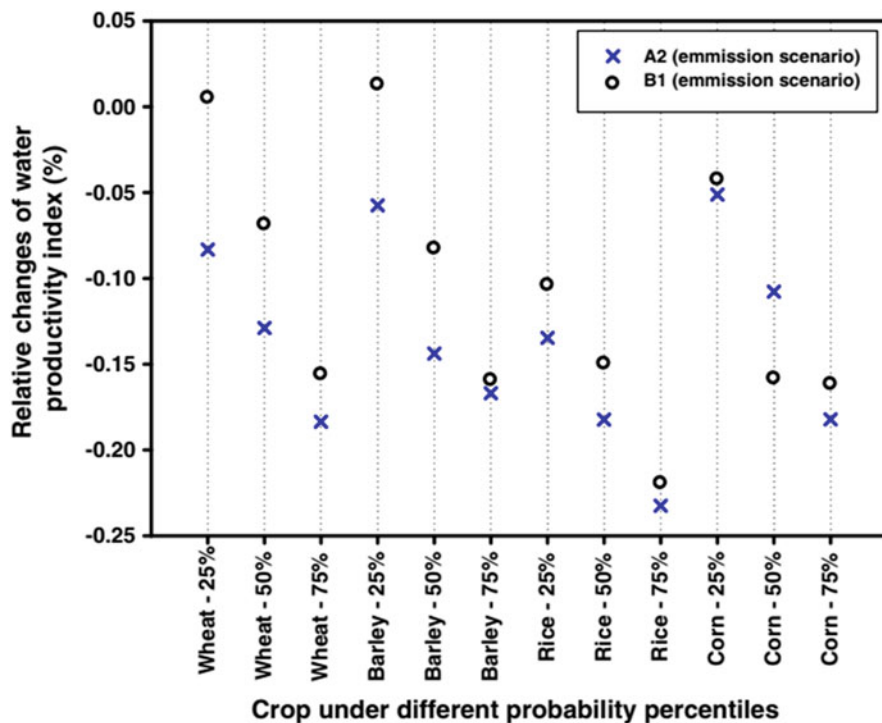


Fig. 1.14 Relative change of the water productivity index under different emission scenarios and probability percentiles until 2044 (Source: Goharia et al. 2013)

Zayandeh Rud Valley from the late Tertiary to Quaternary. They examined the spatial structure of a representative area of the valley in three dimensions, determined responsible geological and geomorphic processes of landscape formation and investigated inherited records and evidences of changes in soil development. During the last century, intensified drought resulted in a vigorous driving force to desertify the eastern part of the basin. This aggressive process is now the most important degradation factor in this valley.

Batani (2013) shows with a remote sensing analysis in the basin, that between 1997 and 2008, bare lands increased from 5.8% to 20%, while rangelands decreased from 70% to 55%. The results of this study also revealed that degradation of rangeland leads indirectly to the degradation of water quality. Regarding the water quality, in Chap. 9 of this volume Chamani and Karimian show how the Zayandeh Rud River has been subjected to an extensive discharge of wastewater and effluents from several points and nonpoint pollution sources. They studied the sediment quality of the river. A significant rise was observed in the level of river pollutants and ecological risk downstream of Isfahan City, especially after the wastewater treatment plant where any water withdrawal for agricultural and livestock purposes significantly elevates the risk of food-chain contamination with heavy metals. From

a methodological point of view, Chamani and Karimian's work underscores the usefulness of chemical pollution indices in representing the spatial distribution of heavy metals.

Aghasi et al. shed light on the environmental contamination in the vicinity of the almost dried up Gavkhuni wetland in Chap. 10 of this book, using the kriging method. The main objectives were to investigate the spatial distribution of soil properties, determine the spatial variations of heavy metals deposition rates in samples collected from the vicinity of the Gavkhuni wetland, and compare heavy metal concentrations among atmospheric dusts, Gavkhuni wetland sediments, and soil surface in the study area. They also asked whether the annual dusts produced in the area were affected by the dry sediments of the Gavkhuni wetland.

The chapters presented above provide a solid overview of environmental and water-related issues in the Zayandeh Rud catchment. It is obvious that from the Zayandeh Rud dam to the lower reaches where the Gavkhuni wetland is located, the situation is becoming more precarious, and that the agricultural sector—as the biggest water consumer—requires particular attention.

1.4.2 Adaptation Strategies for the Zayandeh Rud Catchment

The Zayandeh Rud basin has been and will continue to be facing the impacts of water resources overexploitation, poor land and water management, and climatic change. Emerging conflicts between and within water using sectors as well as increasing pollution of water bodies make firm responses in the region necessary. In this regard, comprehensive evaluation of water resources using virtually reliable methods at appropriate spatial and temporal scales may lead to a sound understanding of water and land resources and their ecosystems and an optimal management of the watersheds. Scientific results of climate change impacts on the Zayandeh Rud basin's climate variables can provide the basis for such appropriate management strategies (Zareian et al. 2016; Eslamian et al. 2017). In the past years, challenges causing water stress with declining surface and groundwater resources and higher water demand have already led to several adaptation strategies at different management levels in the basin (Hoogesteger 2005; Mohajeri and Horlemann 2017; Ebrahimnia and Bibalan 2017; Torfe et al. 2017).

However, the complexity of social and hydrological macro–micro interactions has made a successful governmentally owned and driven adaptation process of water management difficult. In Chap. 2, Mohajeri shows how sublime theoretical management approaches for Iran's water resources have been jeopardized by impractical policies. Sustainability is a buzzword in many political documents but falls short of expectations.

Multilevel governance patterns, which allow interest groups to participate in the sharing of water by forms of cross-scaled co-management, are required in the Zayandeh Rud (Molle et al. 2009). Integrated Water Resources Management (IWRM) is an approach for facilitating a trans- and inter-sectoral sound response

towards water management issues. The need for such an integrated approach as well as characteristics, challenges, and success of its application in the Zayandeh Rud Basin are discussed in Horlemann et al. (2018) and Mohajeri and Horlemann (2017). Chap. 11 provided by Grundmann et al. presents the results of two consecutive, interactive workshops carried out in 2016 (with farmers and their representatives) and 2017 (with farmers, representatives, academia, and administration) in the framework of the IWRM Zayandeh Rud project, financed by the German Federal Ministry of Education and Research. The recommendations acquired in these workshops build the foundation for a strategy for agricultural transformation in the catchment. The chapter also presents the participatory methods (citizens' juries, SWOT and TOWS, SPA) used in the workshops and shows how these were adapted to local conditions.

To highlight the need and current state of play, particularly in the downstream region of the basin, Nishikawa provides a case study that focuses on Varzaneh in Chap. 14, the most easterly city of the Zayandeh Rud basin. Based on the results of semi-structured interviews and life-history interviews in Varzaneh, the author describes and illustrates the inhabitants' responses to the environmental changes in an ecological short history from the 1960s. Following the transformation of the diachronic subsistence activities enabled her to examine the lower basin of Zayandeh Rud in relation to the historical background in Iran and the structure of its society.

Environmental education is the core when it comes to implementing sustainable water management throughout the country. In Chap. 12, Azimpour presents the work of the environmental NGO "Women's Society Against Environmental Pollution" on raising environmental awareness and involving citizens in environmental protection projects in the Zayandeh Rud catchment. People from different social classes participate in the NGO's activities. The NGO's activities include holding social responsibility and participation workshops, empowering women in Isfahan's eastern rural areas, helping to form local NGOs or developing alternative revenue. Currently, the government does not support NGOs much, although the support has increased in the past decade. In some activities, especially programs at national level or obtaining permissions, NGOs need more support.

On the more technical side of adaptive action, a system dynamics model by Gohari et al. (2017) suggests that infrastructural improvements, ecosystem-based regulatory prioritization, and water demand management (e.g., replacing high water demand crops) complemented by supply augmentation, may temporarily alleviate water stress in a basin. The reduction of cropped land and change of cropping patterns are found to be vital strategies in securing yields and reducing the water demands of the agricultural sector in the basin (Massabbavani and Morid 2005).

In order to be able to adjust agricultural activities to increasingly difficult climatic conditions, it is necessary to determine the net water requirement of crops. Salemi et al. (Chap. 15 of this volume) calculate the water demand of autumn and spring plants in the eastern region of the Zayandeh Rud river basin. To do so, the reference evapotranspiration (ET_o) was calculated using FAO Penman–Monteith equation via coding in visual basic (climate sub-model) and zoning using Arc GIS. By establishing the relationship between the landscape units and the climatic parameters

of each synoptic and climatologic meteorological station, ETo amount was measured in rasterized Agricultural Climatically Zone map units. The optimization of computer algorithms and the establishment of a sound database of net water requirements and related maps can help in developing sustainable agricultural sector strategies. Ziaei (Chap. 4 of this volume) elaborates further on the adaptation strategy to reducing farming in the lower reaches of the catchment but also discusses the potentials for greenhouse farming.

In Chap. 16 of this volume, Torabi and Salemi present their ideas on increasing water productivity in the Roodasht area by replacing abiotic stresses with tolerant forages. In the Roodasht region, farming, forage production, animal husbandry, and dairy production are important for meeting nutritional needs. In a time without water restrictions, alfalfa and corn silage have been the main suppliers of livestock forage, but due to high water demand and an inability to use unconventional water (gray water) their production has been severely restricted. In their study, water productivity of sorghum was investigated in a field experiment. The results showed that sustainable production of forage for livestock could be obtained by cultivating sorghum due to its tolerance to abiotic stresses, deep and extant root systems, waxy cover on stem and leaf, as well as the ability to maximize water use efficiency through leaf arrangement and stomatal regulation.

As a functional compilation of adaptive land and water management measures on a local scale, Raber and Reyhani present an Action Plan for the Roodasht region to cope with climate change in Chap. 13 of this volume. Findings of the vulnerability analysis carried out in the project “Feasible Adaptation Strategies for a Sustainable Land Use in the Lower Reaches of the Zayandeh Rud River” (Raber et al. 2018) have been used as the basis for compiling the strategic action plan. The Harvard Negotiation Project approach was used to define and compile adoption measures in a trans- and interdisciplinary participatory process with experts and stakeholders. These defined measures were enriched with international expertise and bundled into sets of concrete measures for reconciling water distribution at basin level, agricultural development, regional management, and the protection of the Gavkhuni wetland. Together, the compiled roadmap is supposed to reduce the vulnerability and strengthen the adaptive capacity of the lower reaches of the Zayandeh Rud towards climatic and socioeconomic change.

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