3 Climate

Ali Khalili and Jaber Rahimi

Abstract

Iran is characterized by an extremely diversified climate, ranging from extra-arid to per-humid type. The main reasons are (a) vast extension of latitude, (b) stretching mountains and tremendous changes in altitude across the country, and finally (c) the position of the land considering seas and adjacent/far water. In this chapter, the effect of these factors on Iran's climate is explained, and main climatic parameters including precipitation, temperature, humidity, solar radiation, wind regime, and prevailing winds are classified, and their spatial/temporal distribution maps are presented. The climate-based zoning of Iran according to the modified de Martonne's classification system shows a rapid decrease from extra-arid toward per-humid in such a way that 64% of the whole country is arid and 20% semi-arid. Hence, Mediterranean to per- humid climate type is limited to 16%. The same study shows the future status of climatic condition during the 2050s and 2080s as becoming drier and warmer. Changes in the percentage of covered areas by different climates and sub-climates are presented quantitatively.

Keywords

Precipitation • Air temperature • Soil climate • Solar radiation • Winds • Humidity
Climate classification • Climate change

3.1 Factors Affecting the Climate of Iran at a Glance

Iran is geographically located in southern half of the temperate belt in northern hemisphere, within the arid and desert belt of the world. Major parts of this area coincide with air subsidence zones in general circulation model of the atmosphere. The deserts of Iran are categorized among the world's driest regions. The climate diversity is extremely high due to: (a) vast expanse of latitude being mountainous with tremendous changes in altitude across the country, and finally (c) the position of the land as related to the adjacent as well as the far water bodies.

3.1.1 Effect of Latitude

The vast expanse of latitude in Iran, from 25 to 40 °N, i.e., about 15°, directly affects solar radiation regime, air temperature, and other climate-related factors. For example, annual mean air temperature varies from 26 °C in Chabahar, at the Oman Sea, to 16 °C in Bandar-e Anzali, at the Caspian Sea borders, while both places nearly have the same elevation. This difference is mainly due to the difference in latitude.

3.1.2 Effect of Topography

Topography is known as the most important factor in climate diversity. The impact of mountains on climate can be outlined as follows:

A. Khalili (✉) · J. Rahimi
University of Tehran, Tehran, Iran
e-mail: akhalili@ut.ac.ir

M.H. Roozitalab et al. (eds.), *The Soils of Iran*, World Soils Book Series,
https://doi.org/10.1007/978-3-319-69048-3_3

- First, the great mountain chains, Alborz in the north and the western Zagros mountains, act as walls. Alborz causes the rising of humid air masses above the Caspian Sea or North Atlantic over the hillsides and extensive precipitation over the northern coastal area. Western Zagros range, on the other hand, obstructs the western humid air masses. This condition theoretically causes warm and dry winds on the lee sides of Zagros (Föhn phenomenon), and in further areas, it leads to arid condition, depending on the distance from the sea.
- Second, the mountainous heights, either as chains or as single, play a recognized role in reduction in temperature and increase in precipitation. Main points of these changes in mathematical equations of temperature and precipitation are reflected in Sects. 3.3.2 and 3.4.1.

The range of heights in Iran is from about 25 m under the sea level at the coastal areas of Caspian Sea to about 5600 m at Central Alborz chain. Figure 3.1 displays topography and location of meteorological stations referenced in the text.

3.1.3 Position of the Land as Related to Seas

The impact of great water bodies on the climate is twofold, including "the adjacent seas" and "the distant seas." The Caspian Sea, Persian Gulf, and Oman Sea are categorized in the first category, and the Mediterranean Sea, Black Sea, Indian Ocean, Atlantic Ocean, and the Red Sea in the second one. Prominent effect of the Caspian Sea is noticeable in a widespread region that stretches from Astara to the end of Gorgan Plain, which is situated between the foothills of Alborz mountain range and the sea. In this area, there is a type of humid to per-humid, moderate climate, and at higher areas cold humid to very cold humid climate. Reduction of temperature and a high amount of rainfall are known as traits of this kind of climate.

The role of the seas located in the south of the country, with respect to lower latitude and to the absence of rugged mountains that can act as a wall against wind flow, is not comparable with the situation in the Caspian Sea's coastal region, in terms of annual rainfall.

Its effect is dependent on the existence of special synoptic conditions. Under such conditions, relative intensity of showers and instant precipitation in southern regions are much higher than in central and northern regions. However, general climatic impact of the seas and the distance from the mean be explained in slight fluctuations in temperature and humidity during the year, in high vapor pressure throughout the coastal plains and in local wind regime.

The role of distant seas can mainly be summarized in supplying humidity of western moist flows, which are dependent on external low-pressure systems. Finally, the effect of Indian Ocean on the climate is dependent on monsoon's southeastern flows that reach Balochistan region and the southeastern part of the country in summers, with the frequency of four to five years in average. This causes heavy summer rainfalls in this region.

Effects of the monsoonal flows coming from the Indian Ocean into Iran are to notice in August at rainfall regime of southeastern stations, which is stretched to Fasa and Darab. Humidity resulting from the monsoon flows with a frequency of eight years, in August penetrates even to Tehran.

3.2 Air Masses

The types, sources, and tracks of air mass penetration to Iran during the warm and cold seasons of the year are shown in Fig. 3.2.

3.3 Precipitation

3.3.1 Source of Precipitation

General source of precipitation comes from the humid air flows moving across the country along with low-pressure centers, with a west to east direction, during a period of approximately seven months/year, from mid-October until mid-April. A major portion of these low-pressures directly come from the Mediterranean Sea (64%), another part from the North Atlantic Ocean, after crossing over the Caucasus or Black Sea (13%), and finally another portion that after crossing over the Red Sea and Persian Gulf reach Iran (23%).

In addition, in mid-scale, two other sources for regional precipitation in Iran are (1) advection of the polar air masses over the Caspian Sea that include main portion of the precipitation on the Caspian Sea coastal plains, especially in November and December (Khalili 1973), and (2) occasionally penetration of seasonal humid flows of the Indian Ocean in the summer from southeast of the country. The main location for generating rainy low pressures in Iran is mainly at central and eastern Mediterranean (the Aegean Sea). Some researchers point out that the existence of Zagros mountains is effective on low-pressure centers generation in the region (Alijani 1981).

3.3.2 Precipitation Variation with Altitude

Investigation into the variation of mean annual precipitation with altitude in order to draw isohyetal map was carried out based on a network consisting of 1441 stations (Khalili and Rahimi 2014). In this study, Iran is divided into 17 zones, 16 zones of which show positive linear altitudinal gradient (at

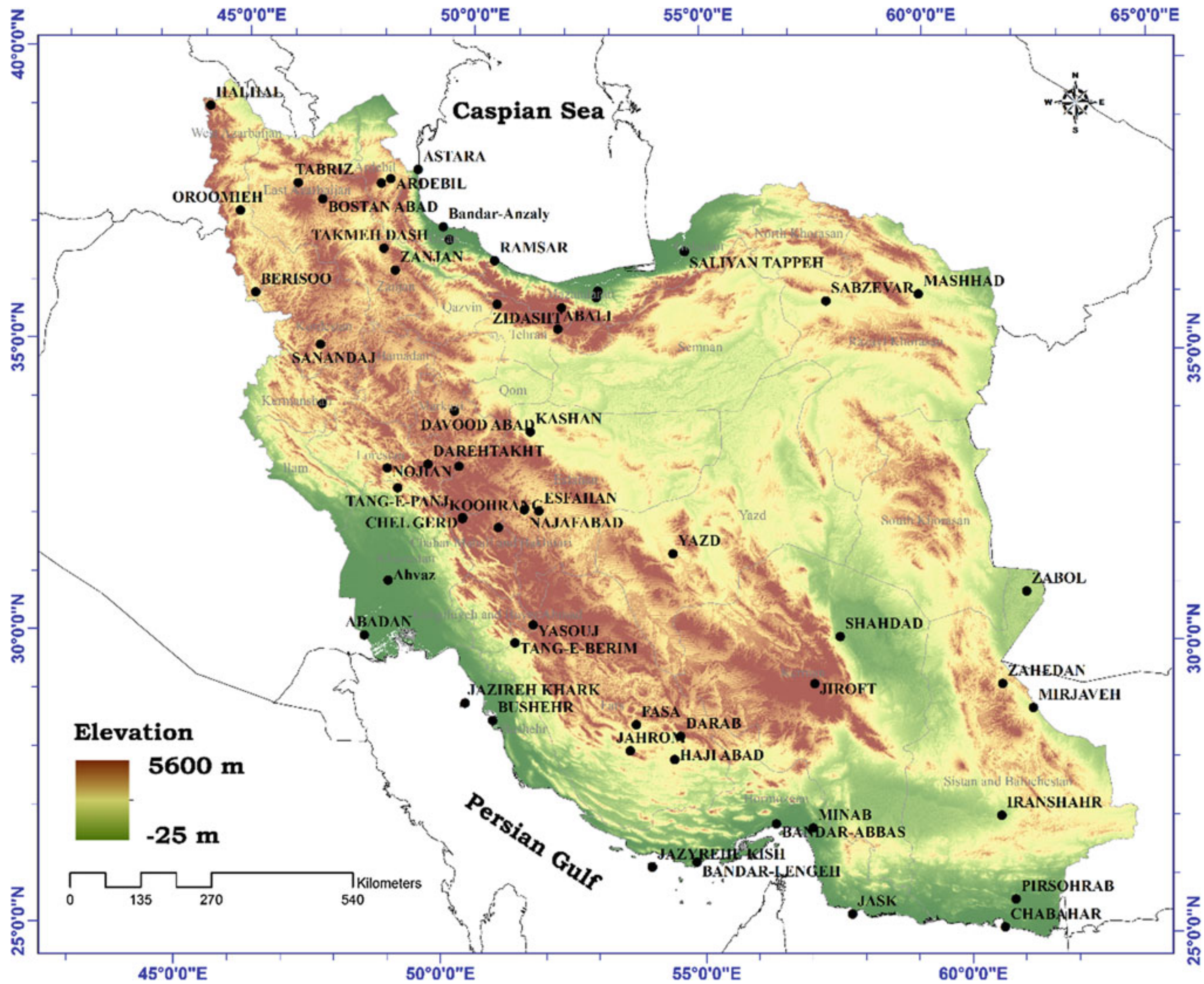

Fig. 3.1 Topography of Iran and location of typical meteorological stations cited in the text (Khalili 2005)

least significant at 5%). These gradients vary between 75 and 573 mm/km in various regions. In the coastal zone of the Caspian Sea to ridgeline of the Alborz chain, the correlation between precipitation and altitude is from second-degree type, which means that the precipitation reduces until a specific height (about 1000 m) and then increases again. This reduction is due to the dominant effect of proximity to the seas compared to altitude effect. The subsequent increase is due to the stronger influence of the altitude effect over the effect of distance from the sea. The annual isohyetal map of Iran with resolution of 1 × 1 km (Fig. 3.3) is the result of the study.

The amount of annual precipitation in the Iranian plateau ranges from 13 to 2003 mm per year. Lut Desert with <25 mm, southwest of Caspian Sea with 1500 mm, and Jazmurian pit and other extra-arid regions with <100 mm are a few cores to mention.

Areas of the country that annually receive precipitation between 100 and 200 mm are almost continuous areas stretching between mountains and coastal regions of the Persian Gulf and Oman Sea, or between central deserts and low-height or semi-high mountains of Alborz, Zagros, and central ranges. A major section of lands with good agricultural capability in Iran is located in the areas where annual precipitation is between 300 and 400 mm, which includes Azerbaijan Plain, northern Khorasan, slopes of Alborz, east/west of Zagros chain, and central mountains. At the group of areas with high level of precipitation in Iran, coasts of the Caspian Sea, heights of Alborz, branches of western river basins (e.g., Chelgard, 1400 mm), and some parts of Iran and Turkey border can be mentioned. The average of annual precipitation in Iran (Fig. 3.3) is 254 mm.

At a general view, precipitation in Iran decreases from the west to east and from north and south to the center. Figure 3.4 depicts precipitation height profile of Iran along the parallel 33°N, between border of Iraq and Afghanistan (A1A2), with resolution of 1 × 1 kilometer. This profile

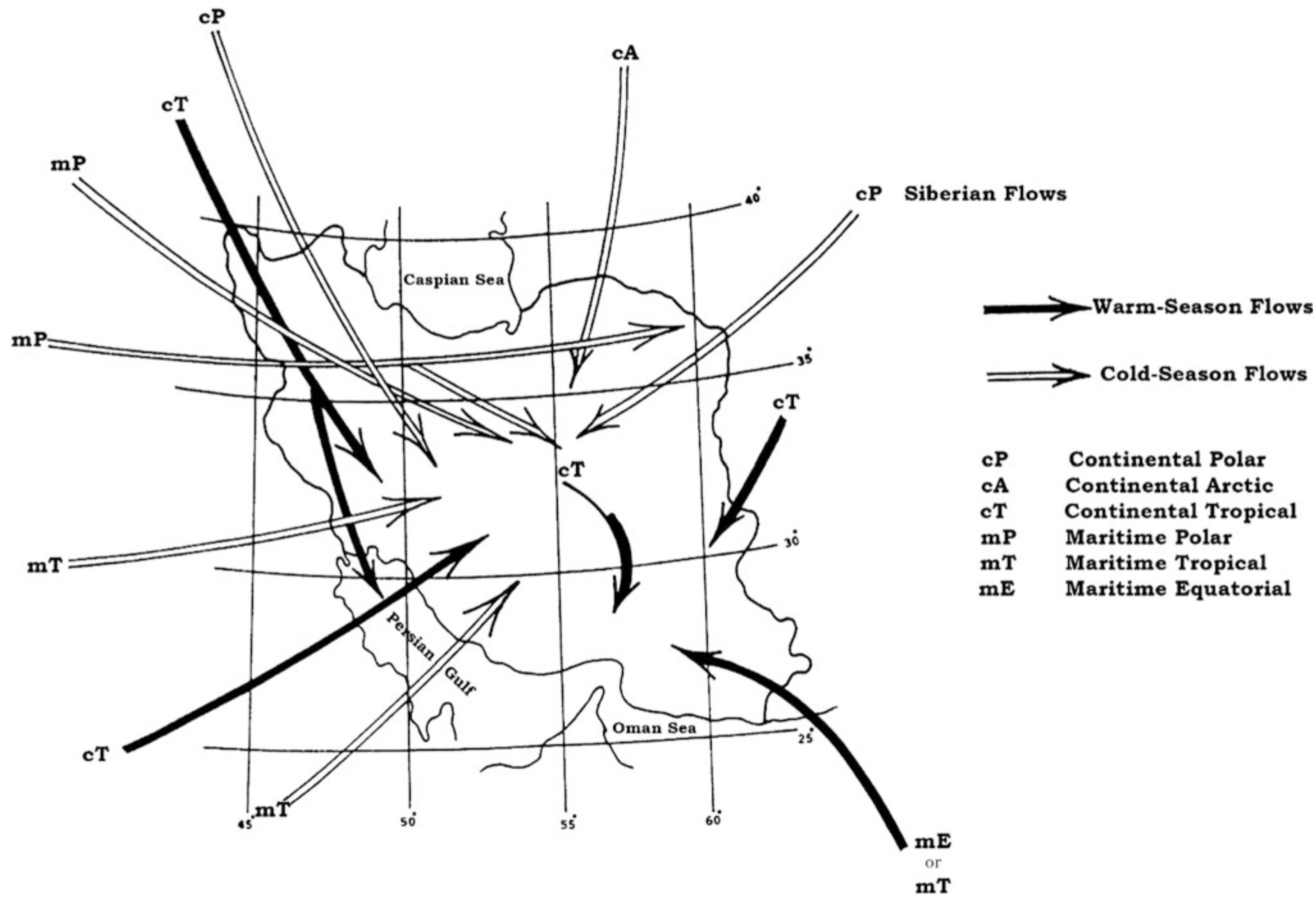

Fig. 3.2 Source regions and paths of various air masses over Iran (Khalili 2005)

appropriately displays the effective height of the Zagros chain influence. Moreover, it properly reflects the general effect of distance from the sea, unequal role of heights, and difference of altitudinal gradient of precipitation at different points of the country. In this Fig. 3.3b, another profile of precipitation height has been presented along meridian 49 ° E (B1B2), between the Caspian Sea and Persian Gulf, which especially reveals different roles of these two great water bodies' area.

Overall, the precipitation in Iran, except for the Caspian Sea coastal regions, is irregular. More irregularity is observed in the drier regions. The coefficient of variation (CV) for annual precipitation in Iran at coastal areas of the Caspian Sea is approximately 20%, while in the interior of the plateau, its values increase and in the Shahdad, located at Dasht-e Lut border, reach 80% (Khalili 1973).

3.3.3 Temporal Pattern of Precipitation

Trend of variation of precipitation in different months in Iran is mainly Mediterranean. Regardless of this general view, distribution of precipitation amount in different regions of the country is not uniform, and the occurrence time of the rainiest month as well as the gradient of precipitation versus time during the year and from a month to another month at different areas varies considerably.

Khalili and Rahimi (2014) classified the precipitation regime, divided into groups and subgroups, and in summary "representative types" (Table 3.1). Each type is the average of all studied stations in the region.

3.4 Air Temperature

Climatic parameters of air temperature in Iran are controlled firstly by altitude and then by latitude, and lightly by longitude. Mean annual air temperature network varies from 5.3 °C in Halhal in northwest of Azerbaijan at the height of 2050 m to 28.3 °C in Pir-e-Sohrab in southeast of the country at an altitude of 120 m above sea level.

3.4.1 Spatial Variation of Air Temperature

Studies based on the multivariate correlation analysis have shown that temperature parameters in Iran can be determined

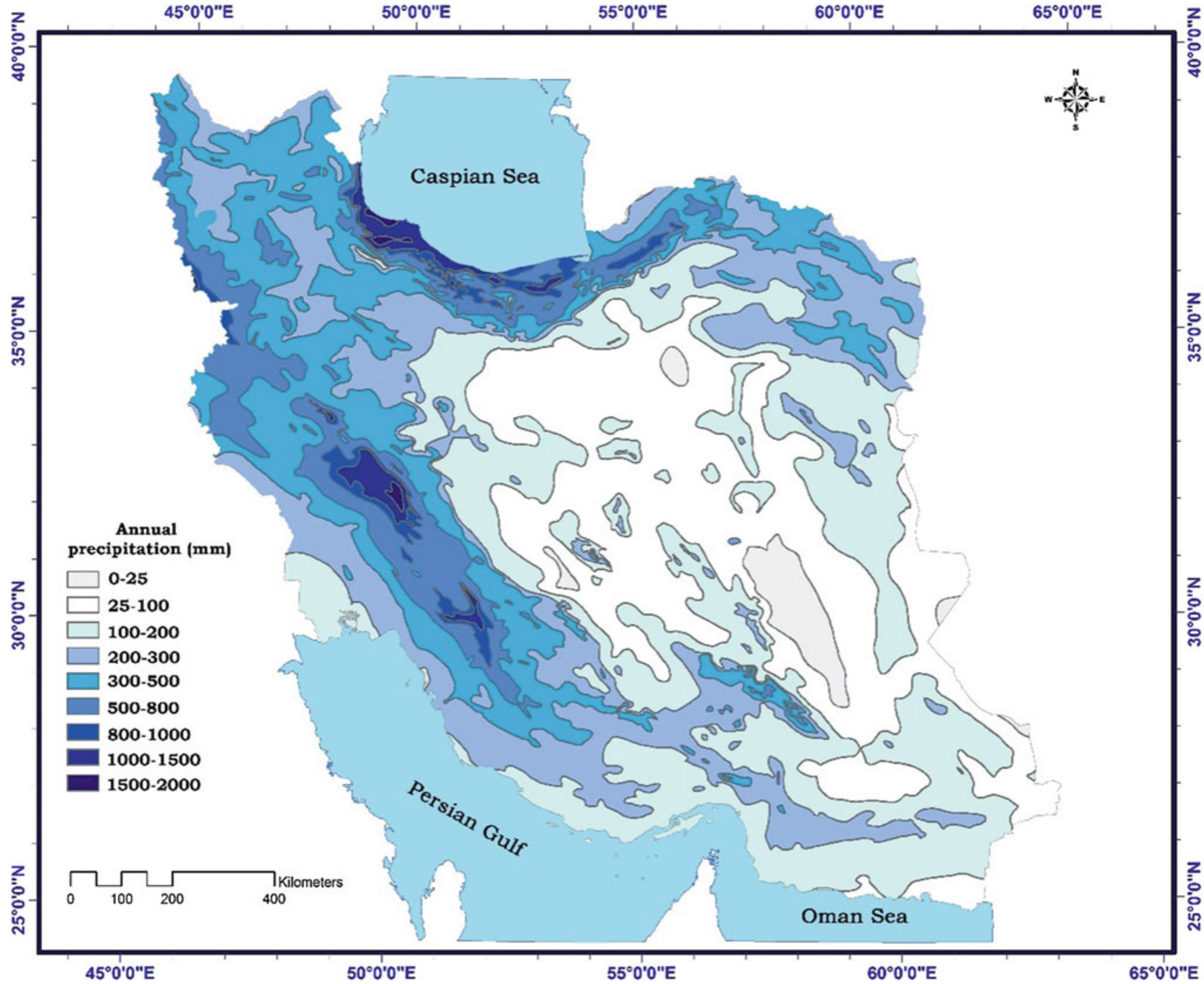

Fig. 3.3 Spatial distribution of precipitation in Iran (1961–2005); only major isohyets map are shown (Khalili and Rahimi 2014)

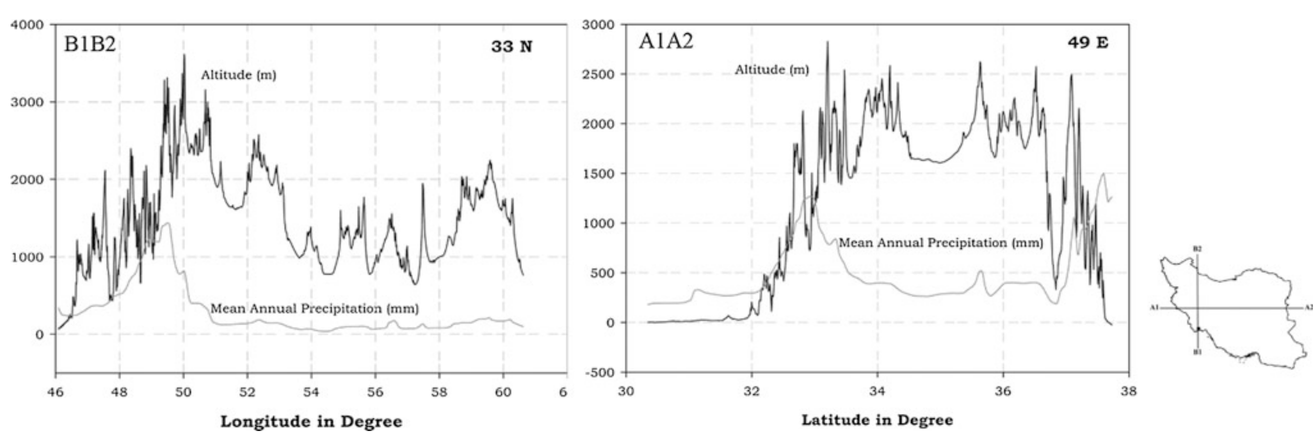

Fig. 3.4 Precipitation height profile of Iran along the latitude 33°N (A1A2) and meridian 49°E (B1B2) (Khalili 2005)

Table 3.1 Classes of precipitation regimes (Khalili and Rahimi 2014)

Types	Description
(a) Caspian sub-Mediterranean types	There is no dry season, at the driest months of the year, on average 25 mm precipitation. Since all months have precipitation, temporal gradient is small. The maximum precipitation in the west and in center occurs at early autumn and in the east at the winter and spring
(b) Spring types	The maximum amount of precipitation takes place in March to April. Azerbaijan, basins of the Lake Urmia and the Aras River, northern Khorasan, and Alborz heights fall under this type
(c) Winter types	Major portion and absolute maximum precipitation in this area occur in the winter, and in addition, precipitation gradient around the maximum is high. Conversely, summer season is completely dry, and no rain sometimes for six months. This regime is dominant type of desert basins and southwest of the country
(d) Mediterranean monsoon types	There is one weak summer maximum resulting from monsoon flows from the Indian Ocean. A prominent example of this regime is in the southeast of the country and mainly at southern Balochistan basins (e.g., Iranshahr)
(e) Winter–spring types	The majority of monthly precipitation occurs with an insignificant difference in one of the months January until April, and increase of precipitation from November until May is gradual. This regime includes mainly the western Zagros, Karkheh, Zab, and Sirvan river basins as well as some high regions of Fars Province

by linear equations that connect the air temperature to longitude, latitude, and height. The number of equations to take into account the three parameters, including mean maximum, mean minimum, and mean daily, is 39 equations. Here, only the equations that are related to the annual temperature are briefly described.

3.4.1.1 A. Mean Annual Air Temperature

The following regression equation of spatial variation of annual mean of daily air temperature (T_{mean}) obtained from 30 years data of 507 stations shows that decrease of normal annual temperature is equal to 5.7 °C per kilometer; in addition, air temperature decreases 0.93 °C as latitude increases each degree from south to north.

$$T_{\text{mean}} = 53.78 - 5.7 \times 10^{-3}Z + 5.9 \times 10^{-3}X - 9.3 \times 10^{-1}Y$$

(Significant at 0.01; $R^2 = 0.914$) where Z is height (m), X is longitude (arc degree), and Y is latitude (arc degree).

Although, the effect of longitude on temperature is negligible and is about 0.01 °C per each degree that can be due to the existence of desert ranges at the center to east and southeast of Iran.

Based on this equation, annual temperature at the heights of 3000 m in northwest of the country is about 1.6 °C, and at the heights of sea level on the southern shores is about 28.0 °C. These two values define the general range of annual long-term normal temperature fluctuations in Iran (Fig. 3.5).

3.4.1.2 b. Mean Annual, Maximum, and Minimum Temperature

The aforementioned method was applied in order to analyze annual normal maximum temperature ($T_{\max}$) and minimum temperature ($T_{\min}$). Three-dimensional regression equation of these parameters is significant at 0.01 and verified as follows (coefficients of determination for these equations are, respectively, 0.925 and 0.815).

$$T_{\max} = 68.66 - 5.6 \times 10^{-3}Z - 1.94 \times 10^{-2}X - 1.119Y$$

$$T_{\min} = 38.90 - 5.9 \times 10^{-3}Z + 3.11 \times 10^{-2}X - 0.741Y$$

These relationships also reveal that the annual average of daily maximum and minimum temperatures at heights of 3000 m in the northwest of the country is 10.4 and −5.3 °C, respectively, and at sea level in the southern Iran is 40.6 and 19.8 °C, respectively.

3.4.1.3 b. Annual Range of Temperature

Annual range of temperature is the difference between daily average of air temperature in the warmest and coolest month of the year. This range for the coastal regions with per-humid climate is much less than for arid areas of the central deserts, because of air humidity that causes adjustment in temperature fluctuations. The mean range of annual temperature (A) at southern coastal areas is low (Bandar Abbas 16.4 °C, Bandar-e Lengeh 16.1 °C), and gradually with going far from the sea, it increases (Hajjiabad 23.8 °C, Jiroft 21.9 °C). In the coastal areas of the north, this law is also observed.

Generally, the amount of A in the coastal areas is about 15 °C, and in cold areas of the northwest as well as the central desert of Iran reaches about 27 °C. Conrad's continentality coefficient (C) was used to measure the effect of air humidity on temperature regime.

$$C = \frac{1.7A}{\text{Sin}(\varphi + 10)} - 14$$

where φ is latitude, and A is range in terms of degree centigrade. This coefficient in the most continental points of the world like Verkhoyansk, Siberia is about 100, and in the maritime tropical regions is around zero.

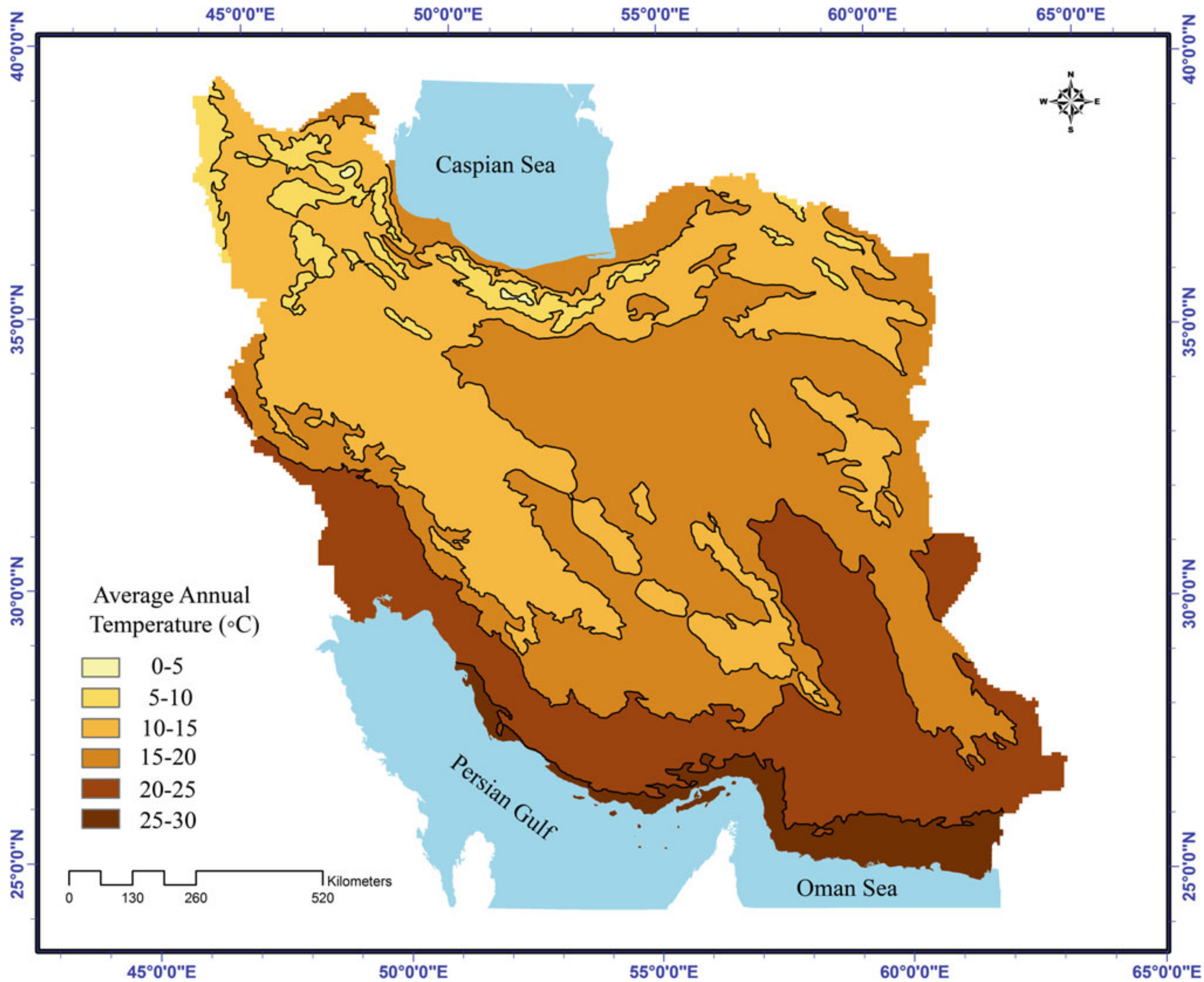

Fig. 3.5 Spatial distribution of mean annual air temperature over Iran (1961–2005) (original work by the authors for the chapter)

In Iran, the "C" value in the coastal zones near the Caspian Sea, Persian Gulf, and Oman Sea is about 24; in cold areas of the northwest, heights of the Zagros are about 50, and in the central desert and Dasht-e-Lut are about 60.

3.4.2 Frosts

In this context, the number of frost days, which are the days in which the daily minimum temperature reaches zero or below, was studied. The most suitable method to estimate the number of frost days in Iran is the relationship between annual mean temperature and the number of frost days. This analysis was performed, and its results are presented as follows:

$$N = 207.9 - 8.7T$$
$$R = 0.91$$
$$n = 249$$

where N is annual mean of the number of frost days; T is annual mean of daily temperature (normal temperature); n is the number of stations; and R is correlation coefficient.

From the 249 stations, Kish, Chabahar, Jask, Bandar-e Lengeh, and Minab are frost free; Bushehr is on average 0.1 frost day (once at 10 years); Bostan Abad (altitude = 1750 m) has the top number, i.e., 169.1 days/year, which is equal to 46% of time over a year. Above equations were used to convert the data to a three-dimensional spatial distribution, the basis for drawing the map of frost day's number considering longitude, latitude, and height or in order to point estimates (Khalili 2005). In general, one-degree increase of annual normal temperature would mean 8.7 days less frost, i.e., the number of annual frost days at the mentioned place minus 8.7.

3.5 Soil Climate

Climate is one of the major state factors controlling soil formation (Jenny 1941). Soil climate regimes, manifest in the combined factors of soil moisture and soil temperature, were defined and are used at different levels in various soil classification systems (e.g., USDA Soil Taxonomy and WRB). Soil moisture regime "refers to the presence or absence of either groundwater or water held at a tension <15 bars in the soil or in specific horizons (soil moisture control section) by periods of the year"; a soil characteristic that plays an important role in the analysis of the state of the soil water. On the other side, also soil temperature controls plant growth and is important for soil formation. Both characteristics can be measured and described, but there also some methods and computer models have been proposed to relate soil moisture to meteorological records (USDA 1975). The best-known computer program is that of Newhall (1972), written in COBOL language, where climatic data of several years are used to simulate the soil climatic conditions. In 1976, van Wambeke (1976) set up a research perspective, and while strictly followed the same principles proposed by Newhall, published a paper to introduce some subdivisions of the soil moisture regimes worked out in a software written in BASIC language, known under the name NSM. The BASIC software differs in its approach from the original Newhall model by using average years (http://www.css.cornell.edu/faculty/dgr2/research/nsm/nsm.html). NSM was used by Banaei (1987), in cooperation with Ghent University, Belgium to prepare the soil climate map of Iran at the scale of 1:2,500,000. The required climatic data of 300 meteorological stations were used to run the program; the results of which were combined in a GIS environment to produce the map.

In another attempt, Sabziparvar et al. (2010) used 10-year (1996–2005) daily meteorological data to investigate the relationship between soil temperatures at standard depths of 5–100 cm and meteorological parameters in four climate types of Iran. The results showed strong correlations (Table 3.2).

Investigating the table values shows that in arid and semi-arid climates, the higher the air temperatures, the more differences between air and soil temperatures are. Based on the regression analysis of 18 stations' data over Iran, the following relationship was obtained which is significant at 1%.

$\mathrm{MAST} = 2.34 + 1.07\mathrm{MAAT}$.

Considering the slope of regression line in this equation, abovementioned difference is a little more than 2 °C in Iran. Using the results combined with the isothermal map of the country, mean annual soil temperature map at depth of 50 cm was prepared (Fig. 3.6).

According to this map, 0.24, 13.44, 52.37, and 33.95% of the country area is covered with frigid (temperature range: 4–8 °C), mesic (temperature range: 8–15 °C), thermic (temperature range: 15–22 °C), and hyperthermic (temperature range: >22 °C) soil types, respectively.

Khalili et al. (2012) have also worked on "freezing depth" as one of the important climatic indices in the soil science and concluded that SHAW model is the best model for estimating maximum soil frost penetration depth, especially during the winter months. Based on their findings, mean maximum soil frost penetration depth at the four stations Shahr-e kord, Urumia, Sanandaj, and Yazd was 22, 9, 21, and 11 cm, respectively. Also, the absolute soil frost penetration depth was 36, 20, 39, and 21 cm, respectively. Soil texture at a depth of 20–50 cm in Shahrekord was silty clay and silty loam in others.

3.6 Air Humidity

Important indicators of air humidity mainly include the relative humidity, vapor pressure, and the amount of these two parameters during the year as well as their trends of

Table 3.2 Main parameters of soil temperature regime in four climate types of Iran (original work by the authors for the chapter)

Climate type	Typical station	Average MAAT	Soil temperature at 50 cm depth[a]				
			MAST	MSST	MWST	MSST-MWST	MAST-MAAT
Temperate–humid	Rasht–Sari	17.2	19.5	25.3	10.7	14.6	2.3
Cold semi-arid	Tabriz–Urmia	12.1	15.2	26	5.2	20.8	3.1
Warm semi-arid	Isfahan–Shiraz	17.1	21.6	30.7	13.2	17.5	3.8
Warm-arid	Yazd–Zahedan	18.8	24	33.2	14	19.2	5.1

[a]MAST (mean annual soil temperature in °C); MWST (mean soil temperature in winter °C); MSST (mean soil temperature in summer °C) all at a depth of 50 cm below soil surface

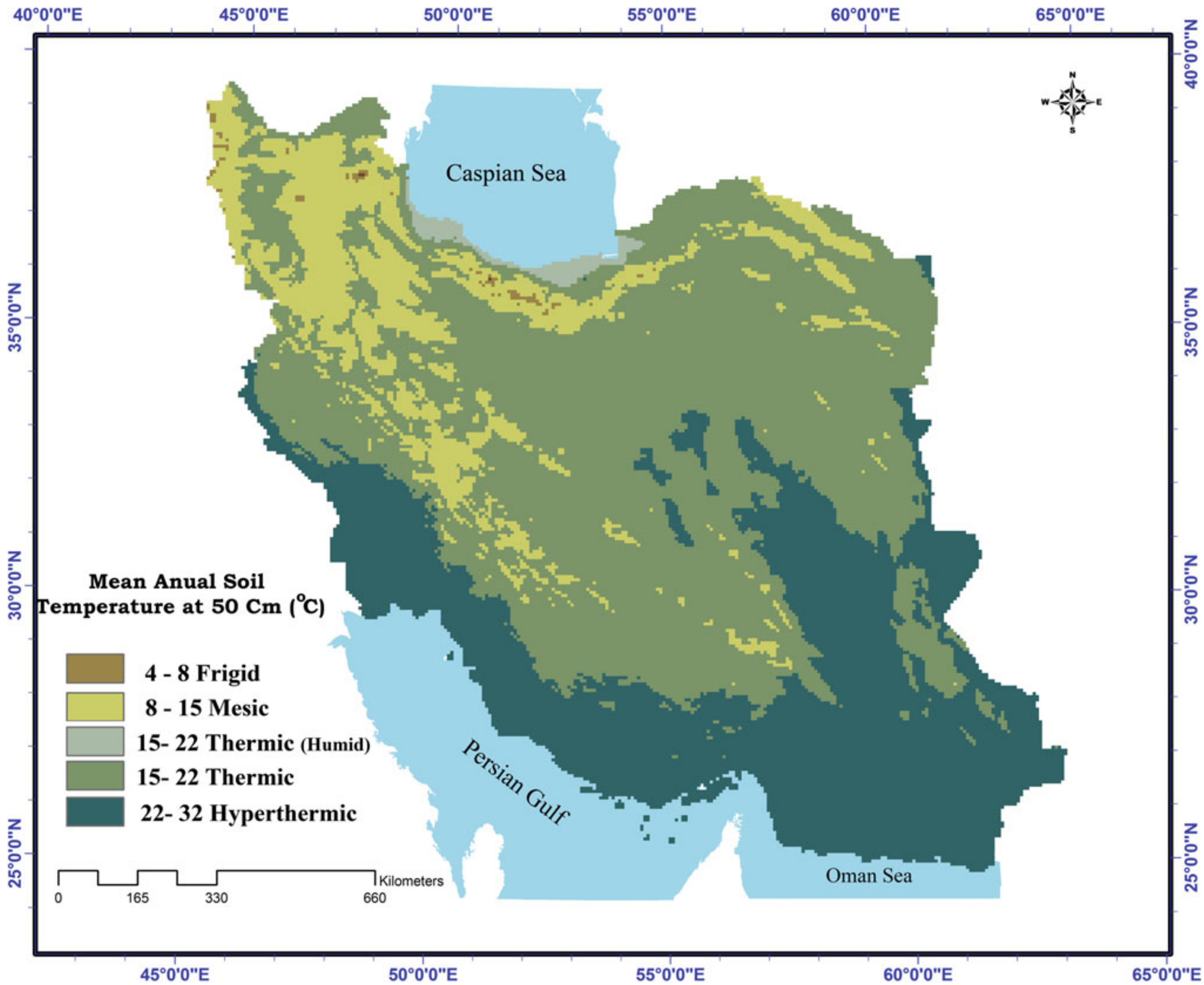

Fig. 3.6 Spatial distribution of soil temperature regime over Iran (original work by the authors for the chapter)

fluctuations, relative to the distance from the sea, proximity to mountains, and the presence/absence of vegetation coverage.

3.6.1 Relative Humidity

The annual average of relative humidity in Iran swings between 29% in Mirjaveh to 85% in Qaran talar at the coastal plains, near the Caspian Sea (Table 3.3).

Review of trends indicates that (1) in the southern coasts, the air relative humidity reflects two peaks, one in the winter (February) and another one in the summer (August). An appropriate sample of this regime is that of Bandar Abbas. And (2) in other areas of the country, the amount of relative humidity in the winter is maximum and in the summer is minimum, with high domain of humidity fluctuations. The monthly average of relative humidity in Yazd in the summer is about 17%, while in the semi-arid regions or the areas with Mediterranean climate, located in the west, such as Kermanshah, this minimum reaches about 20–25%. In the mountainous areas like Abali, the minimum amount extends more, even up to 30%.

3.6.2 Water Vapor Pressure

The amount of vapor pressure, similar to relative humidity, is dependent on the distance to seas and on vegetation coverage in the surroundings. The vapor pressure in different stations in winter is lower than in summer. Also, Persian Gulf's coast tends to have a higher vapor pressure than the Caspian Sea regions. For examples, variations in the monthly average of water vapor pressure in Bandar Abbas

Table 3.3 Variation of mean annual relative humidity (%) in Iran based on the data of 249 stations (Khalili 2005)

Relative humidity parameter	Morning (6:30 LT)		Noon (12:30 LT)		Afternoon (18:30 LT)		Mean	
	Station	Value	Station	Value	Station	Value	Station	Value
Min Max	Mirjaveh Rasht	39.3 93.8	Zahedan Chabahar	22.1 78.5	Yazd Ghoran talar	25.5 87.6	Mirjaveh Ghoran talar	29.4 84.7
Mean SD	65.0 12.0		44.3 13.2		50.6 14.1		53.3 12.7	

(Persian Gulf coast) are 13–35 mbar, in Bandar-e Anzali (Caspian Sea coastal areas) 7–25 mbar, and in Yazd, Tehran, and Kermanshah (Central Iran Plateau) 4–10 mbar.

3.7 Solar Radiation

Direct measurement of solar radiation intensity is merely taken in few weather stations in Iran; among them, the data of 17 stations can be processed from climatic point of view. The lowest amount of received energy is related to Ramsar with an annual average of 283 cal.cm^{-2} day^{-1}, and the highest value is associated with Yazd with an annual average of 507 cal.cm^{-2} day^{-1}. In order to estimate the amount of received solar radiation (Rs) in other stations, angstrom relationship between Rs from one hand and sunshine duration/cloudiness from the other hand was adjusted and applied. Therefore, the amount of received solar radiation was prepared for a network of 85 stations (Khalili and Rezaee Sadr 1997). Figure 3.7 indicates the main isolines of annual radiation in Iran that have been drawn with above-mentioned considerations.

3.8 Winds

In order to give an overall view concerning the winds in Iran, the data from 75 synoptic stations were assessed that their statistics period were more than five years. Average speed of winds is tabulated (Table 3.4), with a remark that average speed in summers is two to four times greater than in winters.

Regarding prevailing wind, that is the direction of the wind with the highest frequency, 62% of the prevailing winds blow from western sector (including northwestern and southwestern winds). The northern prevailing winds have the lowest frequency and can be seen purely at 3% of stations.

3.9 The Climate of Iran

3.9.1 Iran's Climate Zones in Modified de Martonne System

Iran's climatical classification has been done so far at different scales and various systems. For example, Ganji (1954), Shafi Javadi (1966), Sabeti (1969), and Khalili et al. (1992) (Fig.3.8) can be mentioned. The last classification is done at the Integrated Water Plan of Iran using 1100 rain gauge stations and 507 stations for temperature as is shown in Fig. 3.8.

De Martonne's original classification is based on aridity index (A_i), ($A_i = \frac{P}{T+10}$), where P and T are mean annual precipitation (mm) and mean annual temperature °C), respectively. Values of A_i were categorized and resulted in seven groups, from arid to per-humid. Names and thresholds of aridity index classes are presented in the columns 1–3 of Table 3.5.

While maintaining the general skeleton of the de Martonne's aridity index, Khalili (1997) came up with a modification where more classes are foreseen. Table 3.5 illustrates the areas (in %) of the different climate and sub-climate types according to the proposed modified system. A quick review of this table shows that 36% of the country area is covered with extra-arid climate, and 29% is associated with the arid deserts; in general, 65% of whole country lands are under arid climate. Semi-arid climate covers about 20%. Hence, the portion Mediterranean climate to per-humid climate totally is limited to 16%.

Mentioned sample stations in Table 3.5 provide a clear picture of necessity for climate separation of climate types into thermal sub-climate types, the modification that is applied. For example, although the climate of both Koohrang (2650 m) and Bandar-e Anzali (−21 m and close to the Caspian Sea) are categorized as per-humid B (A7 class), their vegetation coverage and flora are different. While in the

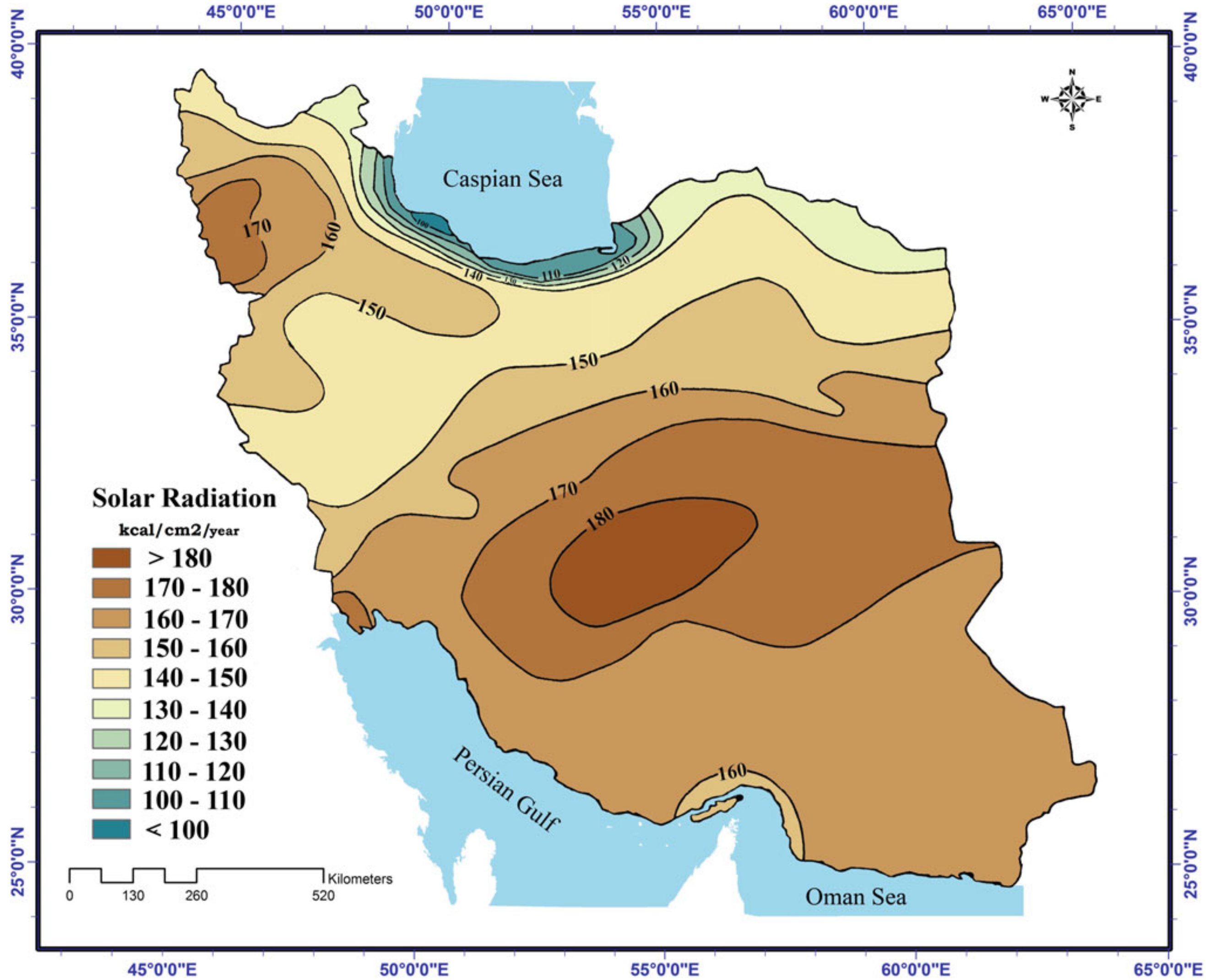

Fig. 3.7 Mean annual global radiation on horizontal surface (Khalili and Rezaee Sadr 1997)

Table 3.4 Range of variation in mean wind speed in Iran (m/s) (Khalili 2005)

Parameter	Annual mean		Mean of June		Mean of January	
	Station	Value	Station	Value	Station	Value
Min	Kashan	0.6	Kashan	0.8	Kashan	0.2
Max	Zabol	4.8	Zabol	9.1	Jazireh Khark	4.3
Mean	All stations	2.3	All stations	2.8	All stations	1.8
SD	All stations	0.9	All stations	1.8	All stations	0.9

modified classification, Koohrang and Bandar-e Anzali are categorized as per-humid B-very cold (A7m1) and per-humid B-moderate (A7m3) climate, respectively.

3.9.2 Climate Change in Iran

In Iran, alike many other countries, studies have been carried out on climate change, whether in form of trend analysis of

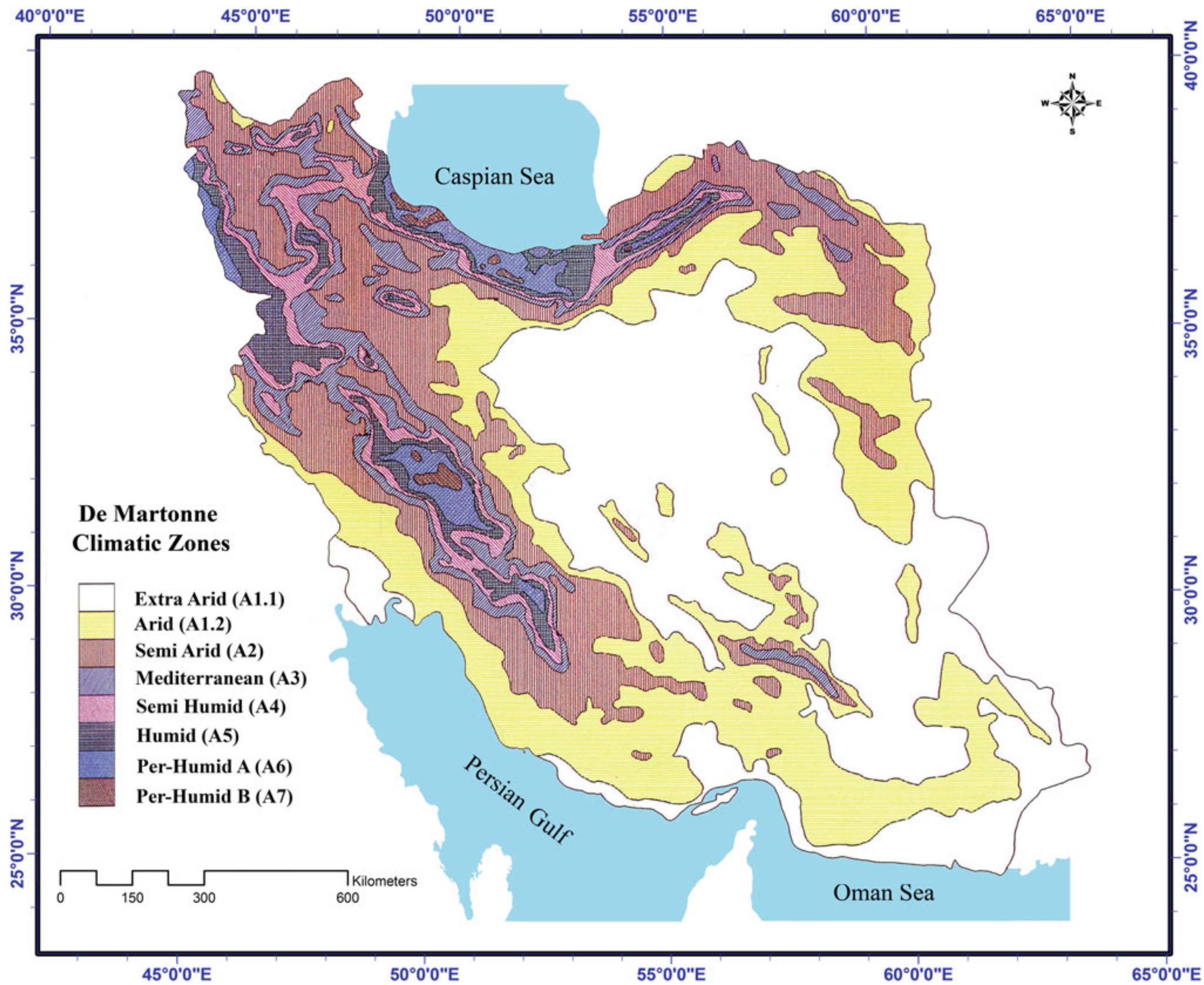

Fig. 3.8 Climate zones of Iran based on original de Martonne classification system (Khalili 1997)

historical climate parameters (Tabari et al. 2011; Kousari and Zarch 2011) or for searching in future climate under different scenarios (Rahimi et al. 2013). In the revision of the Integrated Water Plan of Iran (1997), climate change in terms of mean temperature was considered for 507 meteorological stations in a 30-year period (1965–1995) as baseline temperature; then, consecutive 10-year means of the same network were studied (Table 3.6).

Besides, Rahimi et al. (2013) evaluated the future status of climatic zones in the country during the 2050s and 2080s, using the modified de Martonne's classification system and concluded that the general tendency is toward drier and warmer climate in the future decade. In Table 3.7, changes in percentage of covered areas by different climate and sub-climate types have been presented during two decades, the 2050s and 2080s, and under the scenarios A1B and A2.k

Table 3.5 Areas of different climates and sub-climates of Iran according to modified de Martonne's classification system (% of total area[a]) (Khalili 2005)

Main climate	Thermal sub-climate	Climate type	Typical station	Areas (%)	
Extra-arid A1.1 (Aridity Index <5)	Very cold ($m < -7$)	A1.1m1	–	0.14	35.54
	Cold ($-7 \leq m < 0$)	A1.1m2	Esfahan	15.1	
	Moderate ($0 \leq m < 5$)	A1.1m3	Shahdad	13.9	
	Warm ($m \geq 5$)	A1.1m4	Chabahar	6.4	
Arid desert A1.2 (5 ≤ Aridity Index <10)	Very cold ($m < -7$)	A1.2m1	Davood Abad	1.12	29.15
	Cold ($-7 \leq m < 0$)	A1.2m2	Najaf Abad	16.1	
	Moderate ($0 \leq m < 5$)	A1.2m3	Jahrom	4.76	
	Warm ($m \geq 5$)	A1.2m4	Ahvaz	7.17	
Semi-arid A2 (10 ≤ Aridity Index <20)	Very cold ($m < -7$)	A2m1	Takmeh Dash	6.79	20.08
	Cold ($-7 \leq m < 0$)	A2m2	Zanjan	10.55	
	Moderate ($0 \leq m < 5$)	A2m3	Yazd	2.0	
	Warm ($m \geq 5$)	A2m4	–	0.74	
Mediterranean A3 (20 ≤ Aridity Index <24)	Very cold ($m < -7$)	A3m1	Sarab Hendeh	3.08	4.903
	Moderate ($0 \leq m < 5$)	A3m2	Ardebil	1.5	
	Warm ($m \geq 5$)	A3m3	Tang-e-Berim	0.31	
	Very cold ($m < -7$)	A3m4	–	0.013	
Sub-humid A4 (24 ≤ Aridity Index <28)	Very cold ($m < -7$)	A4m1	Zidasht	2.08	3.375
	Cold ($-7 \leq m < 0$)	A4m2	Berisso	0.95	
	Moderate ($0 \leq m < 5$)	A4m3	–	0.34	
	Warm ($m \geq 5$)	A4m4	–	0.005	
Humid A5 (28 ≤ Aridity Index <35)	Very cold ($m < -7$)	A5m1	Sareine Ardebi	2.01	3.562
	Cold ($-7 \leq m < 0$)	A5m2	Yasouj	1.24	
	Moderate ($0 \leq m < 5$)	A5m3	–	0.31	
	Warm ($m \geq 5$)	A5m4	Tang-Panj	0.002	
Per-humid A A6 (35 ≤ Aridity Index <55)	Very cold ($m < -7$)	A6m1	Darehtakht	1.54	2.93
	Cold ($-7 \leq m < 0$)	A6m2	Nojian	0.98	
	Moderate ($0 \leq m < 5$)	A6m3	Astara	0.41	
	Warm ($m \geq 5$)	A6m4	[b]	0.0	
Per-humid B A7 (Aridity Index ≥ 55)	Very cold ($m < -7$)	A7m1	Koohrang	0.26	0.46
	Cold ($-7 \leq m < 0$)	A7m2	–	0.8	
	Moderate ($0 \leq m < 5$)	A7m3	Bandar-Anzali	0.12	
	Warm ($m \geq 5$)	A7m4	[b]	0.0	

[a]Iran's Area: 1,620,703 km^2, [b]Not to Exists—There Isn't Typical Station

Table 3.6 Trend of changes in the regional averages of daily temperature in the network of Iran's stations in 10-year periods based on the data of 507 stations (°C) (Khalili 1997)

Climatic period	1965–1975	1975–1985	1985–1995	1965–1995
Regional averages of daily Temperature	15.9	16.2	16.3	16.1

Table 3.7 Changes in areas (%) of climate zones of Iran during the twenty-first century under A1B and A2 scenarios (Rahimi et al. 2013)

Climates		Areas (%)							
		2050s				2080s			
		A1B		A2		A1B		A2	
A1.1	m1	+0.2	+10.5	−0.8	+10.1	0.0	+3.8	−0.8	+5.4
	m2	−4.1		−19.2		−4.0		−18.5	
	m3	+9.2		−2.7		+8.0		−2.2	
	m4	+5.2		+26.5		+6.1		+26.9	
A1.2	m1	+0.4	−0.7	−4.0	+1.6	−0.8	+1.4	−3.5	+2.6
	m2	−0.9		−6.3		+0.6		−5.7	
	m3	−0.2		+7.1		+0.3		+7.1	
	m4	0.0		+4.6		+1.5		+4.6	
A2	m1	−6.4	−5.5	−10.4	−6.8	−8.5	−1.5	−10.9	−4.0
	m2	+1.3		+0.1		+1.4		−1.1	
	m3	−0.4		+7.4		−0.2		+6.9	
	m4	0.0		+1.4		0.4		+1.1	
A3	m1	−1.7	−2.1	−2.2	−2.4	−2.0	−1.8	−2.3	−2.0
	m2	−0.5		−0.4		−0.6		−0.5	
	m3	+0.1		+0.6		0.0		+0.5	
	m4	0.0		+0.3		+0.1		+0.3	
A4	m1	−0.8	−1.0	−1.0	−1.2	−0.9	−0.7	−1.0	−0.8
	m2	−0.1		−0.1		−0.2		−0.1	
	m3	−0.1		+0.1		−0.1		+0.1	
	m4	+0.1		+0.2		+0.1		+0.2	
A5	m1	−0.8	−0.9	−0.8	−1.0	−0.8	−0.9	−0.8	−0.9
	m2	−0.1		−0.2		−0.2		−0.2	
	m3	−0.1		−0.1		−0.1		−0.1	
	m4	+0.1		+0.2		+0.1		+0.2	
A6	m1	−0.1	−0.2	−0.1	−0.3	−0.1	−0.3	−0.1	−0.3
	m2	−0.1		−0.1		−0.1		−0.1	
	m3	−0.1		−0.5		−0.2		−0.5	
	m4	0.0		+0.4		+0.1		+0.4	
A7	m1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	m2	0.0		0.0		0.0		0.0	
	m3	0.0		0.0		0.0		0.0	
	m4	0.0		0.0		0.0		0.0	

References

Alijani B (1981) Synoptic origin of precipitation in Iran. Ph.D. thesis, Michigan State University, p 328

Banaei MH (1987) Map of soil moisture and temperature regimes of Iran. Soil and Water Research Institute of Iran, Tehran, Iran

Ganji MH (1954) The climate of Iran. Bulletin de La Socie'te' de Ge'ographie d' Egypte 28:195–298

Shafi Javadi (1966) Distribution climatiques en Iran. Monographie de La Me'te'o, Nationale, Paris

Jenny H (1941) Factors of soil formation. McGraw-Hill, New York

Khalili A (1973) Precipitation patterns of central Elburz. Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B 21(2–3):215–232

Khalili A (1997) Synthesis proceeding of integrated water plan of Iran. Jamab Consulting Engineering Co., Climate Section, The Ministry of Energy, Tehran, Iran

Khalili A (2005) Climate of Iran. In: Banaei et al (eds) The soils of Iran. New achievements in perception, management and use (in Persian). Soil and Water Research Institute of Iran, Tehran, Iran, pp 24–71

Khalili A, Hajam S, Irannejad P (1992) Integrated water plan of Iran. In: Meteorological studies, climatical classification map 1964–1984, vol. 4. Jamab Consulting Engineering Co., The Minisitry of Energy, Tehran

Khalili A, Rahimi J (2014) High-resolution spatiotemporal distribution of precipitation in Iran: a comparative study with three global-precipitation data sets. Theoret Appl Climatol 118(1–2):211–221

Khalili A, Rezaee Sadr H (1997) Estimation of global solar radiation over Iran based on climatological data. Geographical Res 12(3):15–36

Khalili A, Rahimi H, Aghashariatmadary Z (2012) Validation of SHAW model in determination of maximum soil frost penetration depth in typical arid and semi-arid zones of Iran. J Agric Sci Technol 14:1185–1192

Kousari MR, Zarch MAA (2011) Minimum, maximum, and mean annual temperatures, relative humidity, and precipitation trends in arid and semi-arid regions of Iran. Arab J Geosci 4(5–6):907–914

Newhall F (1972) Calculation of soil moisture regimes from the climatic record, Revision 4. USDA Soil conservation service, Washington D.C., USA

Rahimi J, Ebrahimpour M, Khalili A (2013) spatial changes of extended de Martonne climatic zones affected by climate change in Iran. Theoret Appl Climatol 112(3–4):409–418

Sabeti H (1969) Bioclimatic Studies of Iran (in Persian). University of Tehran Press, p 1231

Sabziparvar AA, Tabari H, Aeini A (2010) Estimation of mean daily soil temperature by means of meteorological data in some selected climates of Iran. J Sci Technol Agric Nat Resour 14(52):125–138

Tabari H, Somee BS, Zadeh MR (2011) Testing for long-term trends in climatic variables in Iran. Atmos Res 100(1):132–140

USDA (1975) Soil taxonomy. A Basic system of soil classification for making and interpreting soil surveys. US Government Printing Office, Washington, D.C., USA

van Wambeke A (1976). NSM program to calculate soil moisture and temperature regimes using a mathematical model developed by Newhall F, New York State College of Agriculture and Life Sciences, Cornell University Soil Management Support Services, Soil Conservation Service, U.S. Dept. of Agriculture, Ithaca, N.Y. Washington, DC

Author Biographies

Dr. Ali Khalili is professor emeritus of the University of Tehran, Faculty of Agricultural Engineering and technology, Irrigation & Reclamation Engineering Dept. Meteorological Division. He is member of the Academy of Sciences of I.R.I., editor in chief of Journal of Agricultural Meteorology, member of working group on Climate Change and Global Warming in Science Foundation of I.R.I. His current research activities are centered on climate, climate change, extreme climate events risks and agro-climatology.

Dr. Jaber Rahimi is a graduate from Department of Irrigation & Reclamation Engineering (Meteorological Division), University of Tehran. His research interests focus on climate change, extreme climate events, risk assessment, agro climatology, and drought assessment.