Chapter 10
Water Resources in Relation to Climate Change

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Abstract In this chapter, the influence of global climate change on precipitation, water availability, drought conditions, runoff, potential evapotranspiration, soil moisture change, and underground water resources (groundwater) is being described for the efficient management of freshwater resources particularly for agriculture purpose (a major freshwater consuming sector). Climate change impacts can be characterized by considering the variability in most important climatic factors such as precipitation and temperature. The timely occurrence of rainfall during the crop growth period helps to increase the crop yield, minimize the cost of production, and maximize the financial benefit. The temperature variation is conducive to increase the frequency of extreme precipitation or drought events. Some studies have reported that precipitation pattern has changed in the past few decades around the globe. This change indicates the uncertainty in precipitation, i.e., occurrence of heavy precipitation or light and moderate precipitation (flood and drought). A study projected that 14% of global land is facing drought events for every 5 years under 3 °C of global warming, as 5–10 times more frequent drought events were observed in most of Africa, Caribbean, central America, central Asia, west Asia, northwestern China, and Oceania. Similarly, strong and frequent drought events were predicted for the southern, large part of the eastern and western Europe, southern and central America. As a result, dryness will increase and put further stress on the agricultural system. On the other hand, the reduction in drought frequency was observed in northern Europe and Russian Federation. These projected scenarios for future climate change showed uncertainties. No doubt, the uncertainties in projected climate change scenarios always need to be taken into consideration. The implementation and regulation of water policies in future water resources projects should consider the projected climate change and uncertainties scenarios. A better understanding of the process of

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drought and wet spells will lead to better management of agricultural and hydrological activities.

Keywords Climate change · Extreme events projection · Uncertainties · Water resources management

10.1 Introduction

Global freshwater resources like rivers, lakes, and underground aquifers are under stress due to the increasing demand of world populations for drinking, irrigation, and sanitation. Most of the scientific and climate projected studies have proved that climate change is adversely affecting the freshwater resources in different regions of the world (Stagl et al. 2014; Malinowski and Iwona 2018). Change in climate affects the runoff and flood intensity as well as frequency, duration, and intensity of precipitation (Nguyen et al. 2018). These changes have a further impact on the management of water resources and socioeconomic systems. Similarly, global warming and changing climate systems can affect the sea level by melting of snow as well as by thermal expansion of the ocean. Moreover, the northern high latitude glaciers will melt and most of the earth will receive frequent heat waves and heavy precipitation as a result of global warming (Zaffar et al. 2014; Mishra 2019). The glaciers are particularly sensitive to climate change. On the other hand, almost one-sixth population of the world depends on the water flow from mountain glaciers and associated precipitations. The retreating ice and snow will have a remarkable impact on the downstream areas if warming proceeds. Similarly, the drought conditions have increased in some areas due to the more frequent dry spell. Therefore, it is essential to analyze climate change impact on precipitation pattern, water availability, runoff, potential evapotranspiration, soil moisture change, drought condition, and underground water resources for the management of available water resources.

10.2 Temperature Behavior

Climate change can be characterized by the variability of surface air temperature. The earth's temperature has increased by 0.7 °C in the past century alone and it continues to rise. Long-term analysis of historical temperature data indicates that land surface is warming faster than the oceans. Intergovernmental Panel on Climate Change (IPCC) reported that the temperature of the ocean and earth's surface showed a linear trend with warming of 0.85 (0.65–1.06) °C over a period 1980 to 2012 (IPCC 2014). The second half of the twentieth century has turned out to be a particularly warm period and more noticeable changes were observed at high altitude during the spring and winter seasons (Malinowski and Iwona 2018; Sadowski et al. 2013; Majewski and Walczykiewicz 2012). The temperature change trend is conducive to the increase in frequency of extreme precipitation or drought events and occurrence of desertification.

10.3 Global Precipitation Behavior

Precipitation is an important component of weather and climate. It plays an important role in human's everyday life and economy. The timely occurrence of rainfall during the crop growth period helps to increase the crop yield, minimize the cost of production, and maximize the financial benefit. On the other hand, the river flows will increase in response to heavy rainfall. The high river flow contributes to the occurrence of a heavy flood (Almazroui et al. 2017). The flood may become responsible for economic and social losses.

It is particularly important to analyze/understand the current state, change in size, and structure of precipitation at regional, country, and global scales. However, it is difficult to analyze the behavior of precipitation due to unavailability of actual precipitation data for any region with respect to time and space. Some studies have been reported that precipitation pattern has changed in the past few decades around the globe. This change indicates uncertainty in precipitation, i.e., occurrence of heavy precipitation or light and moderate precipitation. Figure 10.1 presents the volumetric change in precipitation over the continents during the last three decades. The analysis indicated that fluctuations in the occurrence of precipitation were

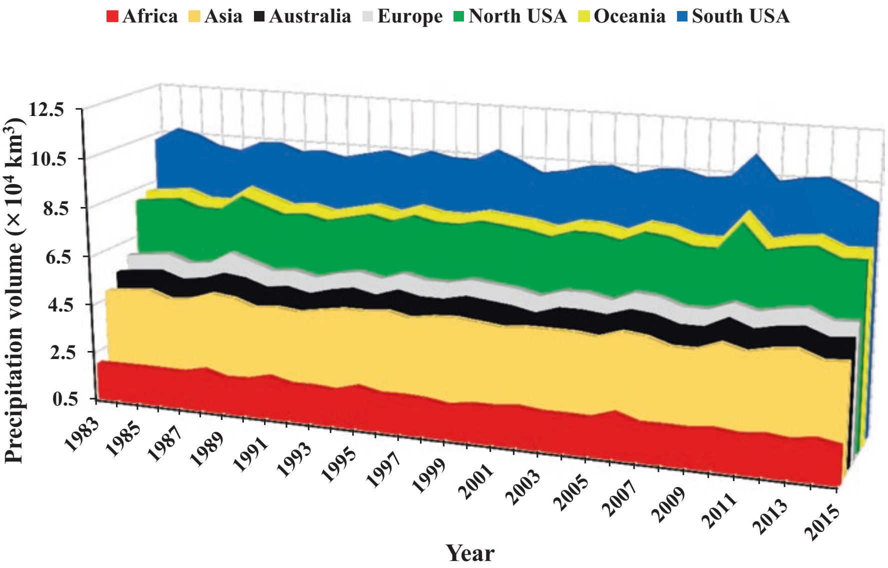

Fig. 10.1 Precipitation volume by Continents (1983–2015)

observed during the whole period but no significant long-term volumetric change in precipitation was observed for either case.

Similarly, Fig. 10.2 showed the comparison of temporal trends of precipitation among the three regions, i.e., north America, south, and east Asia. These regions have an insignificant decreasing trend of precipitation. All the regions with increasing trends cancel out the regions with decreasing trends (northwest to coastal southeast). Figure 10.3 showed the investigation of precipitation trends for management of water resources over the three major basins of the world, i.e., Colorado River Basin, Angola Basin, and Himalayan Basin. The analysis indicated that all three basins showed variability in precipitation over the historical record. The interannual variation in surface temperature also results in variability of global precipitation (Mishra 2019). It was observed that all three basins have been experiencing a decreasing trend for precipitation during the last three decades. Nguyen et al. 2018 analyzed the precipitation behavior over the 237 global basins. The analysis indicated that 20 basins show significant decreasing trends in precipitation whereas 20 basins confirm significant increasing trends. Similarly, statistically insignificant decreasing trends in precipitation were observed over 106 basins and insignificant increasing trends were depicted over 89 basins during the last three decades. This indicated that climate change may occur noticeably especially in terms of precipitation and temperature. If precipitation does not significantly upsurge, there will be more stress on water resources. As a result, dryness will increase and put further stress on the agricultural system.

Tables 10.1 and 10.2 provides the projections of seasonal temperature and precipitation change for the sub-regions of Asia for the three time slices namely 2020s, 2050s, and 2080s using the baseline period of 1961–1990 under the Special Report on Emission Scenarios (SRES) with highest future emission trajectory (A1F1) and

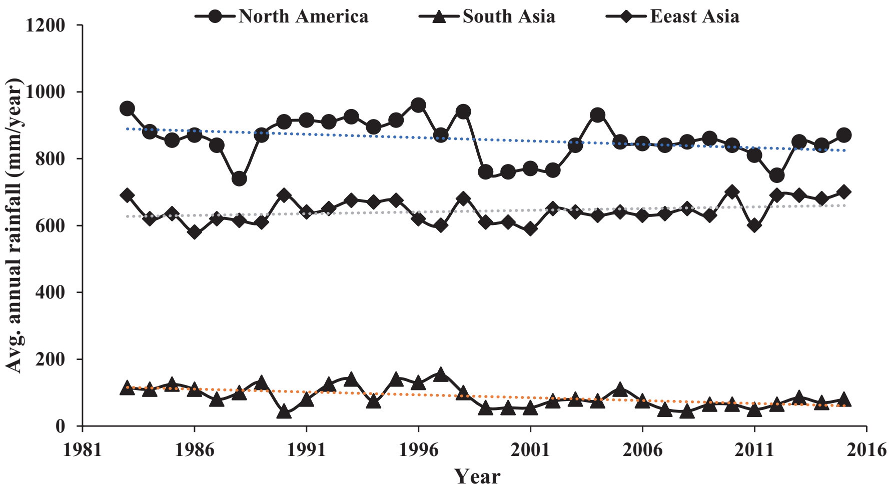

Fig. 10.2 Temporal Trend of rainfall for North America, South, and East Asia

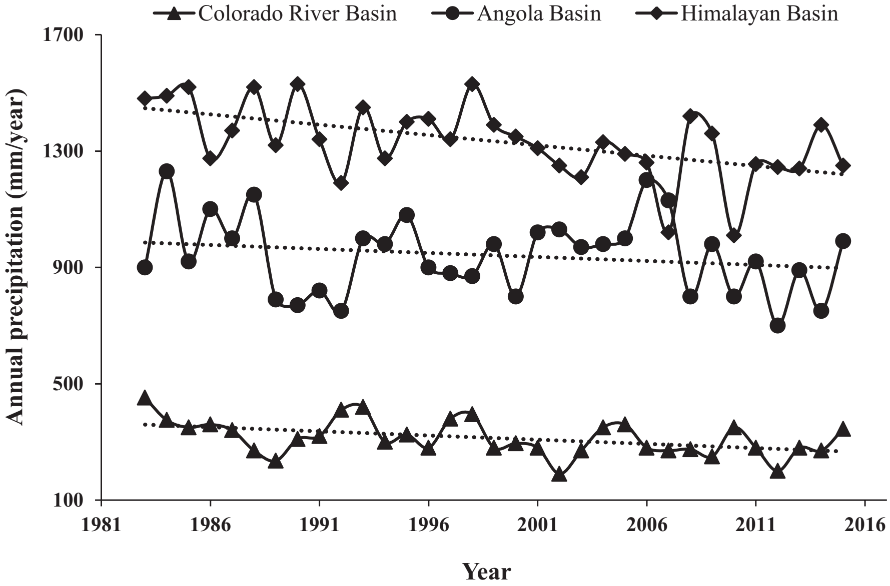

Fig. 10.3 Temporal precipitation trend of three important basins

lowest future emission trajectory (B1) pathways. The annual surface air temperature and precipitation were divided into four seasons based on the 3 months' average such as Summer, Autumn, Winter, and Spring seasons. The higher warming was projected for all the sub-regions of Asia during the northern hemispheric winter than the summer for all the time period. During this century, the maximum noticeable warming was predicted at a high altitude of north Asia and an increasing trend of average annual precipitation was predicted in most of Asia. However, the increasing trend of average annual precipitation was relatively largest and more consistent in the northern and eastern regions of Asia. The projected mean precipitation during the winter will increase in northern Asia and Tibetan Plateau and decrease in central, western, southeastern, western, and eastern regions of Asia. The projected mean precipitation during the summer will increase in northern, southern, southeastern, and eastern regions but it will decrease in western and central regions. It was also observed that due to the very dry summer, the decrease in mean precipitation will be escorted in central Asia. Global warming and precipitation variation may have an impact on crop yield and it will decrease upto 30% by 2050 (Cruz et al. 2007). A recent modeling study confirmed the projection and found a significant warming trend with no change in rainfall in the middle and lower part of the Indus plain (Ahmad et al. 2015). An increasing trend of annual precipitations at four meteorological stations and a decreasing trend at two meteorological stations in the southeastern region of upper Indus plain was observed by Ahmad et al. 2018. Kumar et al. 2016 analyzed the long-term precipitation trends in India and found a significant positive trend during the winter and a significant decreasing trend in monsoon.

Table 10.1 Projected changes in surface air temperature for subregions of Asia under SRES A1F1 (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices namely 2020s, 2050s, and 2080s (Cruz et al. 2007)

		2010–2039		2040–2069		2070–2099	
Subregions	Season	A1F1	B1	A1F1	B1	A1F1	B1
North	DJF	2.94	2.69	6.65	4.25	10.45	5.99
Asia	MAM	1.69	2.02	4.96	3.54	8.32	4.69
50N–67.5N	JJA	1.69	1.88	4.20	3.13	6.94	4.00
40E–170W	SON	2.24	2.15	5.30	3.68	8.29	4.98
Central	DJF	1.82	1.52	3.93	2.60	6.22	3.44
Asia	MAM	1.53	1.52	3.71	2.58	6.24	3.42
30N–50N	JJA	1.86	1.89	4.42	3.12	7.50	4.10
40E–75E	SON	1.72	1.54	3.96	2.74	6.44	3.72
West	DJF	1.26	1.06	3.1	2.0	5.1	2.80
Asia	MAM	1.29	1.24	3.2	2.2	5.6	3.0
12N–42N	JJA	1.55	1.53	3.7	2.5	6.3	2.7
27E–63E	SON	1.48	1.35	3.6	2.2	5.7	3.2
Tibetan	DJF	2.05	1.60	4.44	2.97	7.62	4.09
Plateau	MAM	2.00	1.71	4.42	2.92	7.35	3.95
30N–50N	JJA	1.74	1.72	3.74	2.92	7.20	3.94
75E–100E	SON	1.58	1.49	3.93	2.74	6.77	3.73
East	DJF	1.82	1.50	4.18	2.81	6.95	3.88
Asia	MAM	1.61	1.50	3.81	2.67	6.41	3.69
20N–50N	JJA	1.35	1.31	3.18	2.43	5.48	3.00
100E–150E	SON	1.31	1.24	3.16	2.24	5.51	3.04
South	DJF	1.17	1.11	3.16	1.97	5.44	2.93
Asia	MAM	1.18	1.07	2.97	1.81	5.22	2.71
5N–30N	JJA	0.54	0.55	1.71	0.88	3.14	1.56
65E–100E	SON	0.78	0.83	2.41	1.49	4.19	2.17
Southeast	DJF	0.86	0.72	2.25	1.32	3.92	2.02
Asia	MAM	0.92	0.80	2.32	1.34	3.83	2.04
10S-20N	JJA	0.83	0.74	2.13	1.30	3.61	1.87
100E–150E	SON	0.85	0.75	1.32	1.32	3.72	1.90

DJF December-January-February, *MAM* March-April-May, *JJA* June-July-August, *SON* September-October-November

Table 10.2 Projected changes in precipitation for subregions of Asia under SRES A1F1 (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices namely 2020s, 2050s, and 2080s (Cruz et al. 2007)

Subregions	Season	2010–2039		2040–2069		2070–2099	
		A1F1	B1	A1F1	B1	A1F1	B1
North	DJF	16	14	35	22	59	29
Asia	MAM	10	10	25	19	43	25
50N–67.5N	JJA	4	6	9	8	15	10
40E–170W	SON	7	7	14	11	25	15
Central	DJF	5	1	8	4	10	6
Asia	MAM	3	−2	0	-2	−11	−10
30N–50N	JJA	1	−5	−7	−4	−13	−7
40E–75E	SON	4	0	3	0	1	0
West	DJF	−3	−4	−3	−5	−11	−4
Asia	MAM	−2	−8	−8	−9	−25	−11
12N–42N	JJA	13	5	13	20	32	13
27E–63E	SON	18	13	27	29	52	25
Tibetan	DJF	14	10	21	14	31	18
Plateau	MAM	7	6	15	10	19	14
30N–50N	JJA	4	4	6	8	9	7
75E–100E	SON	6	6	7	5	12	7
East	DJF	6	5	13	10	21	15
Asia	MAM	2	2	9	7	15	10
20N–50N	JJA	2	3	8	5	14	8
100E–150E	SON	0	1	4	2	11	4
South	DJF	−3	4	0	0	−16	−6
Asia	MAM	7	8	26	24	31	20
5N–30N	JJA	5	7	13	11	26	15
65E−100E	SON	1	3	8	6	26	10
Southeast	DJF	−1	1	2	4	6	4
Asia	MAM	0	0	3	3	12	5
10S–20N	JJA	−1	0	0	1	7	1
100E–150E	SON	-2	0	-1	1	7	2

DJF December-January-February, *MAM* March-April-May, *JJA* June-July-August, *SON* September-October-November

In China, Zhang et al. 2012 determined decreasing trends during the spring and autumn while increasing trends during the winter season.

10.4 Drought Conditions and Wet Spells

The understanding of precipitation behavior is important to analyze the drought conditions and wet spells for planning and efficient management of freshwater resources. The analyses of droughts and wet spells are particularly valuable for arid and semiarid regions due to their high spatial and temporal variability. The drought conditions refer to a period of precipitation deficit resulting in a shortage of water. On the other hand, wet spells refer to a period of intense precipitation resulting in surplus water and occasional floods in semiarid and arid regions (Almazroui et al. 2017). Thus, a better understanding of the process of drought and wet spells will lead to better management of agricultural and hydrological activities as well as raise the quality of life.

The drought can be divided into four categories such as 1. Meteorological 2. Agricultural 3. Hydrological, and 4. Socioeconomic droughts (Fig. 10.4). The direct significant reduction in total precipitation in relation to mean precipitation in each area at the scale of days, weeks, and months is called the meteorological drought. The meteorological drought further leads to other drought types. The deficiency of water from several weeks (6–9 months) for plant growth is called the agricultural drought (Brázdil et al. 2018). Behind the meteorological and agricultural droughts, the hydrological drought can be characterized by a shortage of water in streams, lacks, reservoirs, and aquifers and when negative effects of drought appear in the whole society then it can be characterized into socioeconomic drought.

Different studies in different parts of the world analyzed the occurrence of drought and its impacts on human life. It has been reported that severe drought events have been experienced repeatedly throughout history in the near east region. These drought events have a large number of social and environmental impacts, including mass migration, famines, and human deaths. From 1900 to 2004, drought has been ranked first among all the hazards in terms of number of people killed. During the same time, Africa and Asia among the continents can be ranked first based on the drought-affected people. On the country scale, droughts also affected many countries such as Syria, Jordan, Morocco, Iran, and Iraq. The durations of drought period are increasing in arid regions of the world, i.e., average global drought periods are 2 months/°C below 1.5 °C and 4.2 months/°C when approaching 3 °C. If the current warming rate continues, the water deficits will convert to fivefold size for most parts of Australia, southern America, Africa, southern Europe, Caribbean, and northwest china. A significant increase (5–10 times) in drought frequency was predicted in the Mediterranean basin due to warming of the earth (west and southern Asia, Africa, Oceania, and Central America). Similarly, Naumann et al. 2018 analyzed the increase in drought condition due to warming of the earth

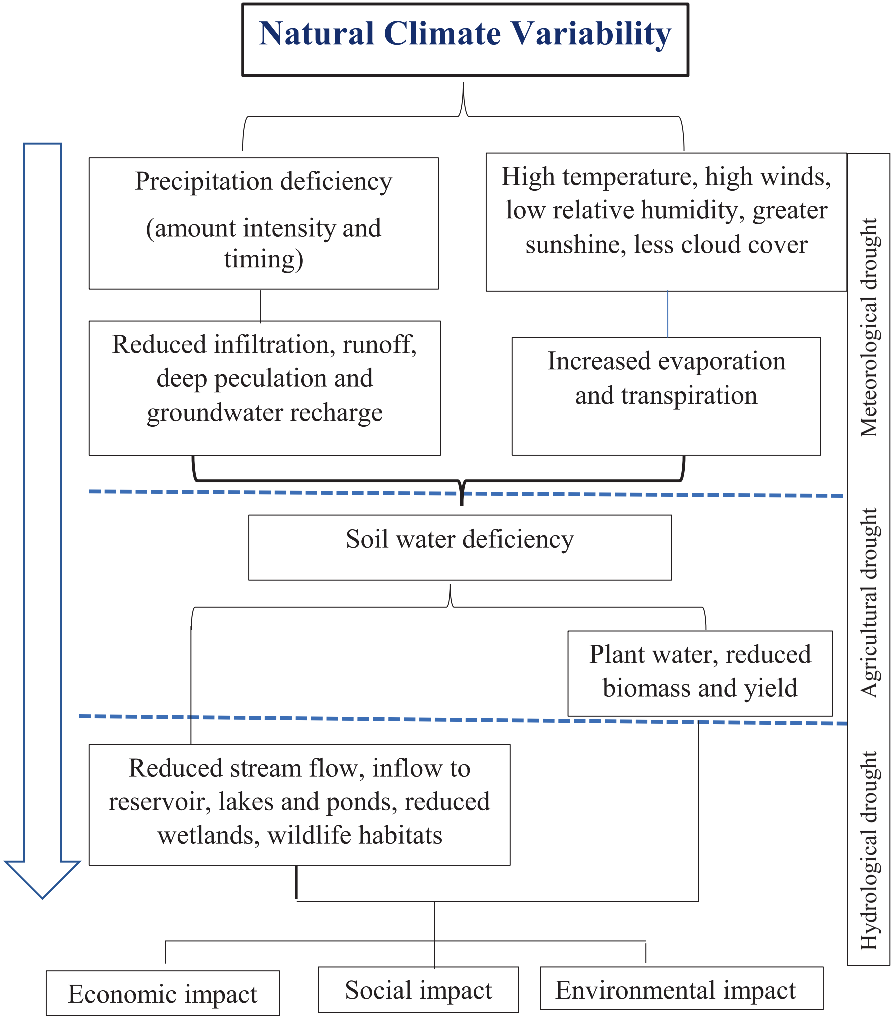

Fig. 10.4 Occurrence and impacts of droughts

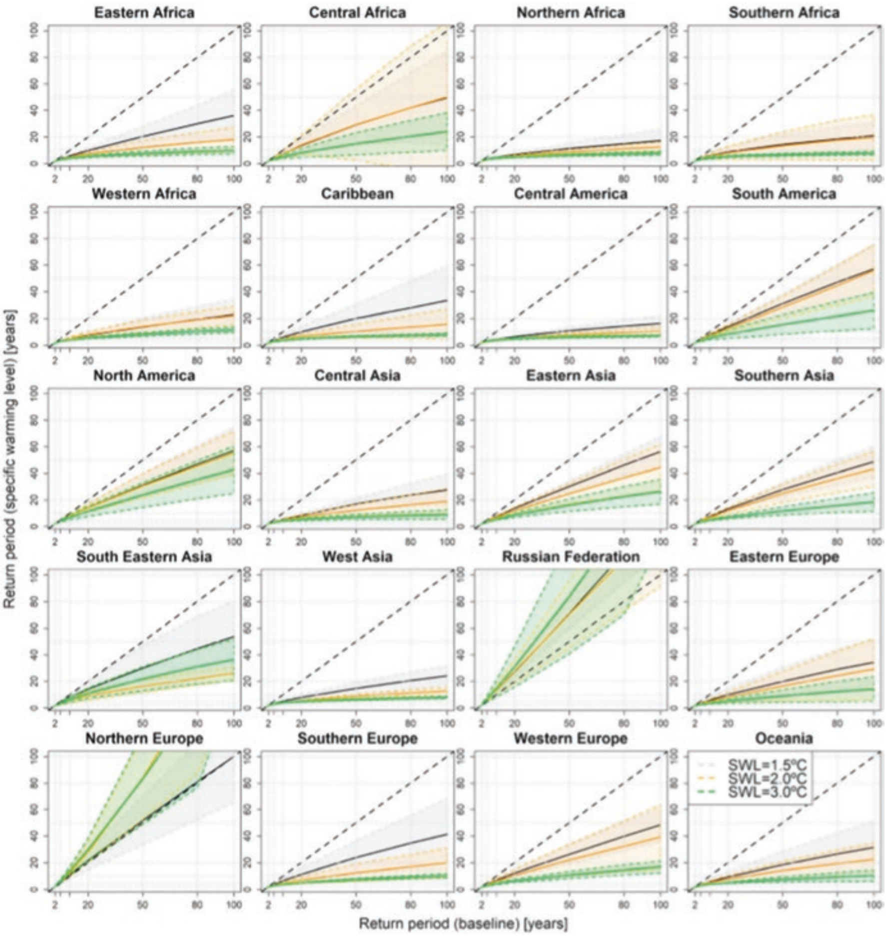

Fig. 10.5 Change in return period of drought in different regions of the world. (Source: Naumann et al. 2018)

and reported that 2/3 of the world's population is being affected by drought condition due to the warming.

Figure 10.5 shows change in return period of drought in different regions of the world. The dashed lines on the graphs (Fig. 10.5) showed no change curve and shaded areas represented the intermodal median absolute deviation for different regions. To a baseline of 100 years, about 15% of the global land may bear droughty events with 5 years interval. As a result, 5–10 times more frequent drought events were projected for most of Africa, Caribbean, central America, central and west Asia, northwest China, and Oceania. Similarly, strong and frequent drought events were predicted for southern, large part of eastern and western Europe, southern and central America. On the other hand, the reduction in drought frequency was observed in northern Europe and Russian Federation (Naumann et al. 2018). These climatic extremes (Drought and flood) are causing considerable economic losses and have a strong social impact on human lives in different parts of the world (Khaliq et al. 2012; Nasim et al. 2012a, b, c).

10.5 Impact of Climate Change on Runoff Change

Climate change and human activities are the most influential factors for global runoff variation including water cycle for any region (Xu et al. 2018). The climate change variation effects on precipitation pattern, which influences urban runoff in such a way that the design of water drainage networks is mainly based on the historical precipitation records and extreme statistics that are assumed to be constant for every year (Zahmatkesh et al. 2018). Moreover, heavy and lower rainfall events increase or decrease the risk of extreme floods and droughts due to climate change in arid or semiarid regions around the globe. Therefore, a better understanding of runoff changes and their potential impacts on water bodies due to climate change is necessary for efficient utilization of freshwater resources. So, Budyko relationship and H08 hydrological model were used across South Asia to simulate the climate elasticity of runoff. The climate elasticity of runoff is a percentage change in a runoff for 1 °C change in temperature or 1% change in potential evaporation or

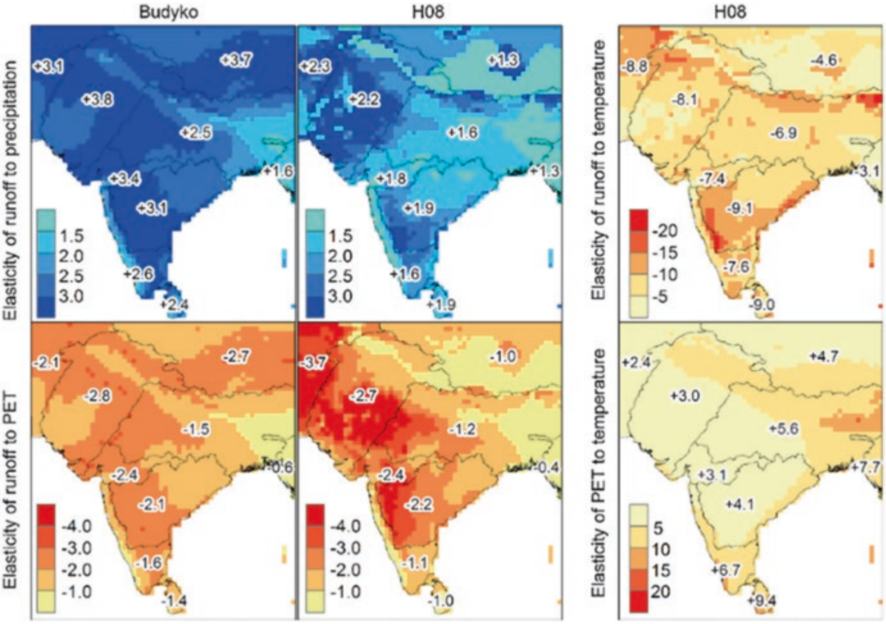

Fig. 10.6 Simulated precipitation, potential evaporation, and temperature elasticities across South Asia (Zheng et al. 2018)

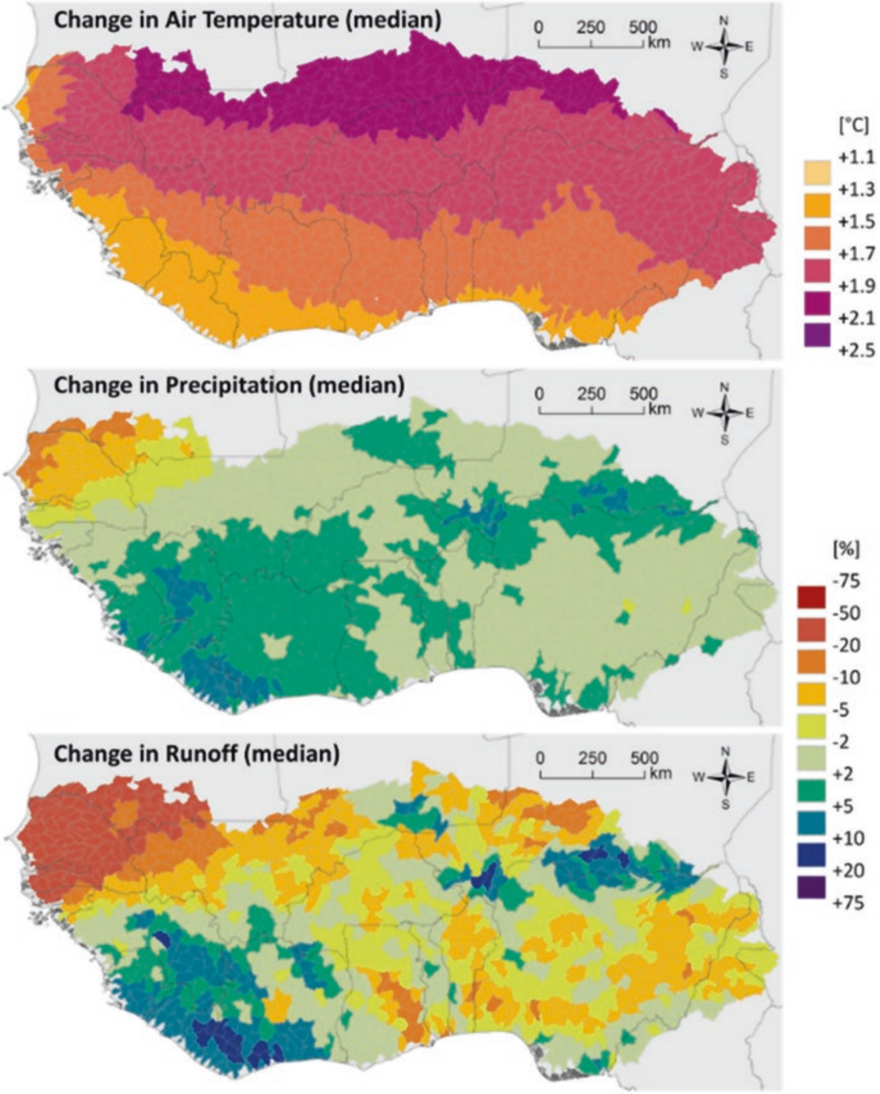

Fig. 10.7 Projected Change for precipitation, temperature, and Runoff in West Africa from 2046–2065 with reference to the simulation data for 1998–2014 (Stanzel et al. 2018)

precipitation (Zheng et al. 2018). In general, both the models showed similar spatial patterns for the precipitation, temperature, and potential evaporation elasticities of runoff. Based on the modeling results, the precipitation elasticity of runoff has been reported in the range of 1.5 or 2.0. This indicated that a 10% change in precipitation can bring a change (15–20%) in the runoff in wetter regions such as northeast, east, and west coast. Similarly, the precipitation elasticity of runoff was found greater than 2 in drier regions such as northwest and inland south. This showed that a 10% change in precipitation can bring 20% change in the runoff in these regions. It was also observed that the spatial pattern for temperature and potential evaporation of elasticities of runoff were found similar. The results showed that a 1 °C rise in temperature can increase the 5% potential evaporation. As a result of an increase in 5% potential evaporation, 5–10% decrease in runoff was observed (Fig. 10.6).

Figure 10.7 shows the projected change for input variables (precipitation and temperature) and for the output variable (runoff) of the water balance model from 2046 to 2065 with reference to the simulation data for 1998 to 2014 in West Africa (Median of 30 model runs). For temperature, the projected median change showed an increase of median change from north to south. The highest warming was projected for arid and semiarid areas in the Sahel region and lowest warming was projected for coastal regions in the middle of this century. For precipitation, most of the area of West Africa showed a median projection in the range of −2 to +2%. The projected median change in precipitation showed a slight increase in precipitation, with values upto 10% in the southwest region of West Africa. The median change in temperature and precipitation exhibits a change in the median runoff. The change in spatial pattern of median runoff is like the precipitation and temperature (Fig. 10.7). The strong warming with lower precipitation showed a strong decrease in the runoff with projected median runoff change −15% in the northwestern region. Similarly, lower warming with substantial precipitation increase showed a considerable increase in runoff in the southwestern coast having median projections >10% (Stanzel et al. 2018). Similarly, several studies have been conducted in other parts of the world to analyze the impact of climate change on runoff variation and reported that water discharge is mainly controlled by the precipitation, temperature, infiltration, and potential evaporation (Naik and Jay 2011; Yao et al. 2015; Xu et al. 2018; Farid et al. 2019).

10.6 Impact of Climate Change on Potential Evapotranspiration (PET)

The role of temperature in the atmosphere is important to quantify the potential change in evapotranspiration (ET) as a result of climate change. The widespread drying in earlier twenty-first century is a clear evidence of increasing PET rate due to climatic variations. The temperature of any region indicates both positive and negative effects on surface and groundwater resources. Global warming trend significantly affects the regional ET pattern, which threatens the utilization of surface water for sustainability (Aladejana et al. 2020). However, very little efforts have been noticed yet to analyze the magnitude and direction of predicted ET from water bodies. It has been studied that the higher temperature in the air increases the ET rate and reduces runoff and soil moisture contents. The minimum temperature in the air decreases the ET rate and increases runoff and soil moisture contents.

Additionally, due to climatic variation, small changes in precipitation and ET may harmfully affect the soil moisture and recharge in arid or semiarid regions around the globe (Ahzegbobor and Kehinde 2017).

10.7 Impact of Climate Change on Soil Moisture (SM) Change

The change of global precipitation and temperature have a significant effect on the SM. Availability of SM and variation in temperature play an important role in terrestrial climate and biochemical reactions in farming lands (Chadha et al. 2019). It has been reported that variability in SM may also affect the groundwater resources and influence atmospheric processes, i.e., cumulus convective rainfall (Thomas and Famiglietti 2019). It has been studied that spatial and temporal patterns in precipitation, ET, and surface water are due to the climatic variables, which affect SM. Other indirect factors that influence the SM contents are land use, land cover, soil texture, slope of the land, and other physiochemical properties of soil (Seneviratne et al. 2010).

10.8 Groundwater

The world's largest fundamental source of freshwater is groundwater (GW), which is a naturally built reservoir under the ground surface and is available for human beings and other sectors (Fig. 10.8). In most of the agrarian countries throughout the world, GW is considered as the foremost source of irrigation (Qazi et al. 2014. Farid et al. 2018). Globally, the 982 km^3/year withdrawal rate of GW was estimated to fulfill drinking and irrigation demands. From the withdrawal rate of GW, about 38% of the land is fortified with GW for irrigation and 60% of worldwide GW withdrawal is used for the agriculture sector. Moreover, from one-third part of all freshwater, GW provides 27% and 36% of water for industrial, and domestic activities all around the globe (Margat and Gun 2013). It is the part of the hydrological cycle and the amount of water which infiltrates into the soil will accumulate on the impermeable strata. The underground layers which both store and transmit groundwater to rivers and sea are named as aquifers. In these GW systems, the water moves slowly in motion from the recharge areas to the discharge areas. Tens or even hundreds of years may pass for this water passage through the hydrological cycle. Water that discharges from the aquifers performs two major roles. First, it benefits the environment by maintaining the river flows. Secondly, it provides water to meet the demands for drinking and industrial use. These aquifers deliver water to rivers during a period of no precipitation. These are natural underground reservoirs and very appropriate resources and can have a massive storage capacity, much greater than even the

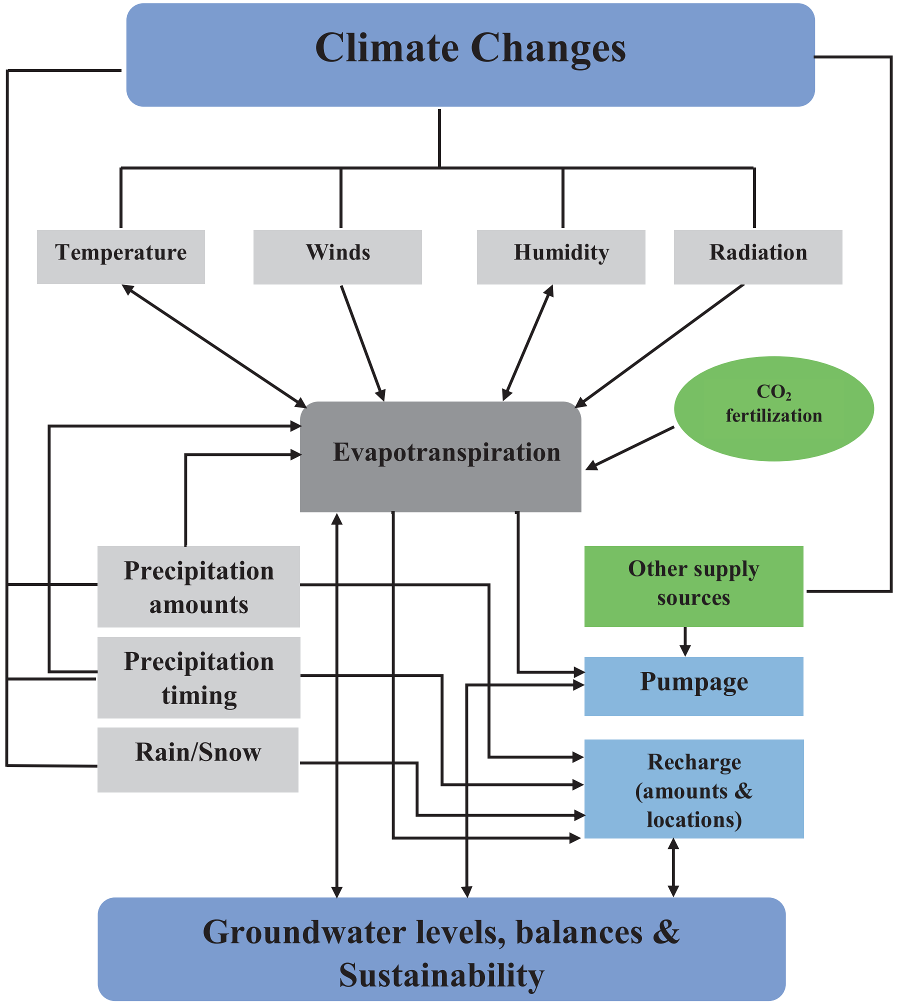

Fig. 10.8 Schematic diagram of groundwater balance and sustainability

largest man-made reservoirs. Due to greenhouse gases, climate change affects the groundwater structures such as it produces stresses to the groundwater recharge and its circulation in time and space. Different researchers have observed that the changing pattern of rainfall and increasing trend in temperature have significant effects on GW recharge and its availability. The increase in temperature means an increase in evaporation and plant transpiration rate. This will give exposure to soil erosion in arid and hot areas. All these pose negative impacts to the groundwater systems. The lowering in GW table due to increasing temperature and changes in rainfall patterns may decrease well efficiency, yield and increase initial pumping cost. The farmer community is extremely affected in those areas, where GW is used as a primary source for irrigation of agricultural lands. Chances of side effects for excessive GW abstraction vary with the situation of the hydrological environment (Fig. 10.8). The extensive weather events can lead to a longer duration of floods and droughts, which then directly affects the availability of GW. Due to the longer duration of floods and droughts, there is a greater risk in depletion of aquifer storage. Therefore, it is essential to quantify the contribution of influencing factors for mastering the GW dynamic and management of GW resources (Li et al. 2020).

Due to the poor maintenance and protection, mostly GW wells are contaminated and in times of emergencies and disasters, these wells will not be able to deliver water to meet freshwater demands. Indirect climate changes also create massive impacts on GW such as the intensification of human activities and land use. Using GW in a more strategic way in a changing climate becomes more and more important. Groundwater recharge is a function of climatic factors, topography, land use, and local geological formation. It has a direct relationship with precipitation. Therefore, it is a vital resource that must be protected so that it will sustain humans and other species for their survival. The degradation in GW occurs due to over-exploitation of GW, which extremely reduces the water table. Due to over-pumping, available GW resources and borehole yields reduce and impart side effects, which include subsidence and saline intrusion. Salinity occurs due to poor irrigation practice and due to the result of poor abstraction. Salinity does not reduce naturally, and it is the main threat to aquifer sustainability. Regardless of its vast importance, GW resources are in crisis for various regions mainly due to the over-exploitation of groundwater to fulfill the irrigation needs and food requirements for increasing population of the world.

10.8.1 Climate Change Impact in Relation to GW Abstraction

The occurrence of GW depletion for a given aquifer can be analyzed when the rate of recharge becomes lower as compared to the discharge rate of GW (Fig. 10.9). Indirectly, changing climatic scenarios in the form of anthropogenic practices of GW pumping, land use pattern, and growing urbanization causes GW depletion. It was analyzed that over-abstraction of GW influences the rise in sea level to some extent. Global warming also causes rise in sea level, if balancing of the system is not

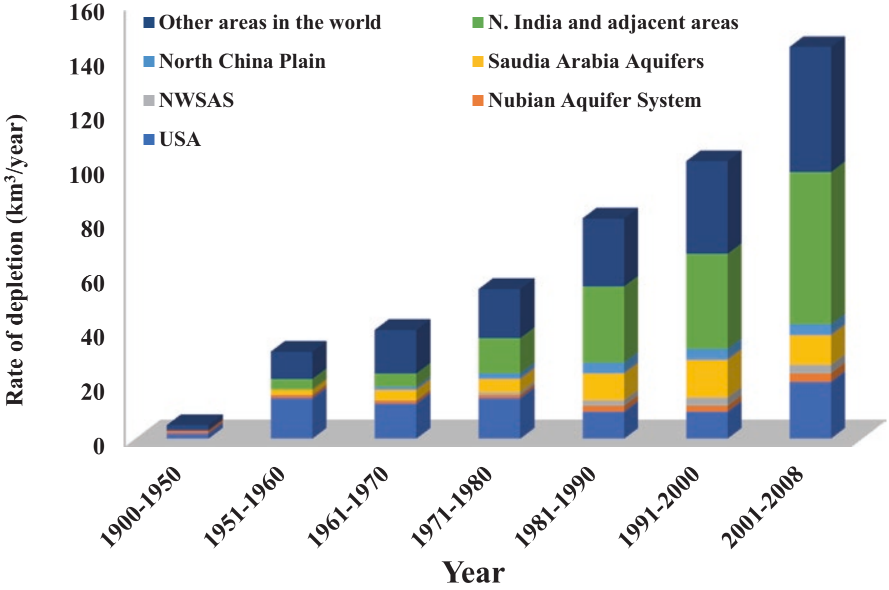

Fig. 10.9 Net groundwater depletion rates around the globe from1900–2008

achieved between the capacity to store water into reservoir and irrigation flow return (Green et al. 2011; Naz et al. 2013; Masood et al. 2013; Mubeen et al. 2013; Saeed et al. 2013; Sultana et al. 2013). The GW resources are being affected by climate change (Aladejana et al. 2020). The occurrence of soil degradation and variability of crop water demand have been influenced by climate change. As a result, the GW discharge/recharge is being affected directly or indirectly (Ho et al. 2016; Foster et al. 2018). A measurable increasing trend in GW depletion has been noticed with increasing population growth and advancement in technology in many regions, where GW resources tend to utilize at many extents. The technological advancement comprises the high-efficiency well pumps, which are used to fulfill water demand that eventually causes the depletion of GW resources (Shakoor et al. 2017; Beck et al. 2018). Furthermore, the quantitive and qualitative gap was found between the GW data collection and analysis which creates difficulty to decide the system for GW resource management). Climatic variations interrupt a GW discharge usually GW discharge increases in arid and semiarid regions. The runoff is a most sensitive hydrological parameter, when it combines with increasing aquifer discharge and winter precipitation, it results in risk of flooding under the wettest climatic condition (Croley and Luukkonen 2013). Correspondingly, an aquifer recharge, which is also a sensitive parameter for the hydrological cycle, decreases in context to dry climatic conditions, resulting in declining the level of GW (Thomas and Famiglietti 2019).

10.8.2 Intrinsic Effect of Climatic Variation on GW Recharge

Rainfall is a basic component of climatic change and it is considered as a primary source for GW recharge. The phenomenon of GW recharge can be analyzed through occurring of precipitation. The GW recharge will not always change in the same way as the rainfall trends change. The factors that affect the recharge are the aquifer type, geology, soils, land cover, and topographic relief. The recharge rate can also be affected by the precipitation type, intensity, and frequency. Also, variation in soil properties and water usage affects groundwater recharge. In high latitude regions, the GW recharge occurs very early due to the spring melt shifts from the spring season to the winter season. But in temperate regions, the annual recharge variation varies on climate and other conditions. There is a significant difference in the summer and winter recharge because GW is a massive component of the global hydrologic cycle. More attention should be paid to climate change effects on recharge. The necessary tools and data required from most of the environments are currently not enough to predict the recharge responses against diverse climate scenarios.

10.8.3 Climate Change Impact on GW Quality

The quality of GW for a given aquifer should be maintained because it provides fresh water to the living population and meet the demands of farming system for irrigation. The change in characteristics of GW at different depths due to increasing air temperature tends to increase the temperature of GW in a shallow aquifer. Likewise, in arid or semiarid regions, due to an increased rate of evapotranspiration, the GW becomes saline. In a region, where the intensity of rainfall is greater, the available pollutants, i.e., pesticides, heavy metals, and inorganic constituents will be washed efficiently on the surface of the soil. At those places, the quality of GW likely to be compromised via the recharging of the aquifer with these surface water bodies. Ultimately, intrusion of poor quality of water takes place in adjacent aquifer (Ho et al. 2016; Shakoor et al. 2017). It has been noticed that comparatively, very few studies have focused on process disturbing the quality of GW. More precisely, entering of water from other resources instead of significantly changing climatic conditions, will affect the GW quality. Moreover, the spatial and temporal variability of precipitation also affects the GW quality. Meanwhile, the rainfall is chemically diluted, which interacts with the dissolved material of an aquifer, causes to change the interaction time, which degrades the quality of GW resources (Ahzegbobor and Kehinde 2017).

Generally, the degradation of GW quality can be explained in three main groups.

1. Injection of contaminated water into the GW during recharging of an aquifer or movement of surface pollutants in the soil and mixing of these impurities in GW, due to deeper percolation.

2. Induction of changing in GW withdrawal produces the movement of water with varying quality. A very common description in this class is seawater intrusion, which increases the salinity of GW and underlies a layer of saline water on fresh GW layer.
3. The quality of GW changes at the mixing stage, where modification in GW regime and inflexing of different contaminants takes place. An example of this group of GW degradation is irrigation return flow in a saline aquifer, which is due to the effect of over fertilizer and pesticide application in the soil.

There is enormous evidence worldwide that explains the vulnerability of GW resources in relation to climate change. However, the effect on surface water resources with changing climatic scenario is recognized to more extent as compared to these effects on GW. The climate system and GW fluctuation, storage, movement, and recharging are not in equilibrium due to which there is a need to assess variation in GW behavior more precisely. The present GW resources in the world are in the position of vulnerability due to spatial and temporal patterns of rainfall, seawater intrusion, over-abstraction and withdrawal of water from an aquifer, rate of evapotranspiration, and interaction of GW surface during recharging or discharging process. In the assessment process, the information relating to climate changes in hydrological variables and their impacts on GW resources are still inadequate or uncertain for different regions in the world.

10.9 Conclusion

The assessment of climate change impacts on worldwide water resources may help for efficient management of these precious resources. Many research studies in different regions of the world analyzed and quantified the effects of climate change on every variable of the hydrological cycle. A better understanding and timely prediction of floods and drought should help to prepare the emergency plan for efficient management of land and water resources. However, a comprehensive plan should be prepared, and action should be taken according to the plan for optimum conservation of freshwater resources. To save the water bodies, a continuous monitoring system is required, and treatment of the domestic wastewater is also required in urban as well as in rural areas to ensure the safe drinking water quality for the global population as well as to save the environment. The relationship between climate change and the quality of GW in relation to GW storage should be established for such places, where contamination and extraction rate is high. More efficient and cost-effective techniques and tools are needed for accurate prediction and quantification of climate change impacts on water resources at the regional and basin-scale. Furthermore, the future water resources development projects, formation, implementation, and regulation of water policies should consider the projected climate change and uncertainties in projection of climate change scenario. This will help to minimize the adverse impact of climate change on water resources and consequently on agricultural production.

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