

# Chapter 4

## Impacts of Climate Change on the Environment, Economy, and Society of China

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**Abstract** This chapter evaluates the characteristics and extent of impacts of modern climate change on the hydrology, ecology, agriculture, health, economy, and society of China. The impacts of climate change on water resources, hydrological processes, the cryosphere, and ocean hydrological processes are analyzed, as well as the impacts on land ecosystems, desertification, and soil erosion. The impact of global sea-level change on marine ecology and the coastal environment is

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comprehensively assessed. The chapter also summarized the impact of climate change on farming, animal husbandry, forestry, aquaculture, and fisheries.

**Keywords** Impact · Climate change · Environment · Economy · Society

## 4.1 Hydrology and Water Resources

The measured discharge of large rivers in China has been decreasing in the past 50 years, with the discharge from the Haihe River and Yellow River being significantly reduced. Human economic activity is still the main reason for the recent changes in river runoff. However, the impact of climate change on discharge is increasing. Along with socioeconomic development, climate change has exacerbated the conflict between water supply and demand in the northern arid regions of China and exacerbated water depletion (due to water quality) of the southern humid regions. Over the last decade, the river discharge in the northwest alpine mountain areas has significantly increased, mainly due to accelerated glacier melting. Because extreme precipitation events have increased, the frequency and volumes of floods have increased, and the scope and intensity of drought have also increased. And sea-level rise has posed serious challenges to flood control in coastal areas.

### 4.1.1 River Discharge and Water Resources

Hydrological observation records from the Yangtze, Yellow, Songhua, and Zhujiang rivers, spanning nearly 100 years, suggest that discharges of these major rivers are decreasing, at rates from 0.5 % per 10 years to 4 % per 10 years (Fig. 4.1). The measured discharges of the Haihe, Yellow, and Liaohe rivers have also significantly decreased, with the Haihe River discharge reduced ~30–70 % (Zhang et al. 2007). The annual average discharge of the middle and lower reaches of the Yangtze River, the upper reaches of the Huaihe River and Nen River, and rivers in Xinjiang has increased by 2–9 % since the 1980s.

Change in measured river discharge is the product of several environmental factors, including land cover changes caused by human social and economic activities (e.g., construction of water conservation projects and urbanization), climate change, and economic and social development. Overall, human social and economic activities have more significant impacts on river discharge in the northern arid regions of China and have limited impacts in the humid southern areas. For example, human social and economic activities are the major reasons for the decreased discharge in the middle reaches of the Yellow River since 1970. Climatic



### **4.1.2 Cryosphere Hydrology**

The impacts of cryosphere changes on the hydrology and ecology in the cold and arid regions of western China have significantly increased. Glacial runoff accounts for  $\sim 22\%$  of river discharge of inland river basins in western China, and the runoff is an important source of freshwater. Research has revealed that glacier runoff plays strong regulatory role in water availability when glacier coverage is over 5% in a watershed. Glacial runoff produces more water in drought years and less water in humid years with lower air temperatures, therefore stabilizing arid oases.

Climate warming has led to increased glacier runoff in the last 50 years. Glacier runoff into the Tarim River and its main tributaries has significantly increased, with at least 1/3 of the increased river discharge coming from increased glacier runoff. The recent increased glacial runoff into the Yangtze River partly compensated for the decrease in the river's discharge. Intensification of glacier ablation and shrinkage has led to the areal expansion of some lakes that are mainly supplied by glacial runoff. In recent years, the frequency of glacier floods and glacial lake outburst floods has increased. Given differences of glacier coverage and glacier changes in each watershed, the impacts of glacial runoff on water resources still need further research, particularly the impact of the process of glacial runoff decrease after increasing during glacier retreat on river runoff needs refinement.

Permafrost degradation has a direct impact on basin's water cycle processes. Disappearance of permafrost, or thickening of the active layer, has caused a decline in the groundwater level (the water level above frozen soil), which results in decreased wetlands, rivers and lakes drying up, and the continued deterioration of the ecological environment. Permafrost degradation also affects the formation of basin groundwater systems, resulting in increased winter river discharge in many of the permafrost-covered regions.

Warming climate has led to a change in the distribution of annual river discharge, with an earlier start of the spring snowmelt process. The date of maximum monthly discharge (snowmelt discharge) of the Crane River (one tributary of the Altai Irtysh River) now occurs approximately one month earlier, with an increased discharge of  $\sim 15\%$ , and summer discharge has decreased in the past 50 years. Climate-related changes in accumulated snowfall can also affect the amount of snowmelt discharge.

### **4.1.3 Sea-Level Rise**

Climate change has had a profound impact on the circulation and thermohaline environment of continental shelf areas of eastern China and the South China Sea. The temperature of coastal waters has shown a consistent warming trend from 1900 to 2008, with the warming rate of  $1.3 \pm 0.30\text{ }^\circ\text{C}/100\text{ years}$  of the eastern continental shelf and northwestern Pacific, which is 2–3 times of the global ocean average

warming, and this warming is closely related to a strengthening of the meridional heat transport of Kuroshio Current [a north-flowing ocean current on the west side of the North Pacific Ocean] (Wu et al. 2012). Another prominent phenomenon in Chinese coastal waters is the salinity of the Bohai Sea. The average salinity of the entire Bohai Sea has increased nearly 2 Psu (salinity unit) from 1961 to 1996. The salinity near the old estuary of the Yellow River in Bohai Bay has increased nearly 10 Psu, mainly caused by the reduction of Yellow River discharge to the Bohai Sea, and increased evaporation (Wu et al. 2004). The evaporation of the East China Sea has significantly increased, by  $\sim 1.2$  cm/year, which has led to continuing loss of freshwater and heat, while the freshwater flux of the South China Sea has weakened, leading to decreased endothermic conditions from 1979 to 2008.

The average sea-level rise along Chinese coastal areas is 2.6 mm/year in the past 30 years, 0.8 mm/year higher than the 1.8 mm/year global average. Sea-level rise leads to aggravated coastal erosion, which has increased significantly since the 1950s. The majority of sandy shores, muddy shores, and coral reefs changed from deposition or stable states to erosional states, and total erosion increased. The average coastal erosion rate is 15–20 m/a from 1976 to 1982 in Hainan Island. Sea-level rise has increased coastal water depths, enhanced wave action, and intensified storm surges. Rising sea level has led to estuarine saltwater wedges upstream, increasing the intensity of seawater intrusion into rivers and aggravating groundwater salinization. This phenomenon is particularly evident near the deltas of major Chinese rivers. Seawater intrusion is more pronounced in coastal cities close to the Yellow Sea and Bohai Sea. Laizhou Bay, in Shandong Province, is one of the regions with the most serious seawater intrusion in China. The rate of intrusion has increased from 46 m/year during 1976–1979 to 404.5 m/year during 1987–1988 in this region. The sea-level rise has significant effects on salinity traced in Pearl River Delta. The traced distance of 250 mg/L of salinity line significantly increased with the upstream runoff frequency increases. The boundary of salinity traced back to the upstream significantly moved under certain upstream runoff conditions and the rise in sea level (Kong et al. 2010).

## 4.2 Terrestrial Ecosystems

Observational evidence increasingly shows that climate change has strongly influenced terrestrial ecosystems. The impacts of recent climate change are faster and more extensive than in any past period.

### 4.2.1 Forests

The structure, composition, distribution, phenology, productivity, and carbon sink behavior of forests have changed in response to climate change. The extent and

optimal distribution range of the Larix, and spruce, fir, red cedar, and other tree species in the Xiaoxing'anling and eastern mountain ranges in Heilongjiang Province have moved northward from 1961 to 2003, due to climate change. The boundary of Larixgmeliniiiii, the Daxing'anling moved northward approximately 1.5° latitude. The north and south boundaries of spruce–fir optimum distribution area moved northward latitude 0.5° and 1.5°. The optimum distribution area of pine moved northward 0.5° latitude (Liu et al. 2007). Climate warming has had a strong impact on the *Betula ermanii* (birch) tundra transition zone in the Changbai Mountains of northeast China, with the distribution from an altitude of 1900–1950 m migrated to 2150 m. The migration of entire populations of *B. ermanii* has recently shifted northward. Alpine meadows and some species in the forest transitional zone, in the Wutai Mountains of Shanxi Province, have shifted to northward with rising regional air temperatures. Shrubs have invaded alpine meadows, and the tree line has risen ~8.5 m per 10 years in the arid valleys of Yunnan Province (Moseley 2006).

The average spring temperature in China has increased by 0.5 °C, and spring has begun 2 days earlier, since the 1980s. Spring will start 3.5 days earlier if the average spring temperature rises by 1 °C. The start of spring would be delayed 4 and 8.8 days if the average spring temperature decreased by 0.5 and 1.0 °C, respectively. The observed start of spring in Shenyang (during 1960–2005) and in Beijing (1950–2004) suggests that the start of spring has occurred earlier with increasing spring air temperature.

#### 4.2.2 Grasslands

Grassland areal extent has been degraded by 2 million hectares per year, mainly caused by droughts in northern China. The change of grassland ecosystems is more pronounced in the Qinghai–Tibet Plateau where the grassland ecosystems are more sensitive to air temperature increase. For example, grassland ecosystems with extreme vulnerability in the source regions of the Yangtze and Yellow rivers have continuously degraded since the 1960s. The area of high-cover alpine meadows and alpine swamp meadows has shrunk by 17.7 and 25.6 % (Wang et al. 2009). Meanwhile, the phenology of dominant plants of alpine meadows has undergone significant changes under climate change. For example, the flowering period of *Elymus nutans* grass, which is the dominant gramineous pasture in subalpine meadows, has advanced 10–14 days from 1985 to 2005, while the maturity period has advanced 20–24 days.

Water is the main limiting factor for grass growth in most parts of China. The productivity of the grassland ecosystem is mainly affected by precipitation. Increased precipitation improves soil moisture supply and enhances the photosynthesis rate, resulting in improved grassland productivity (Li et al. 2008). For example, the net primary productivity (NPP) of grasslands during the growing season in Inner Mongolia increased between 1982 and 2003, while the grassland productivity in typical cross-zone of agriculture and graze in northern China

evidently increased. Reduced precipitation leads to declined grassland productivity. Such as in the pastoral districts of southern Qinghai Province and Gansu Province, middle of Ningxia, the Naqu district of Tibet, and pan regions of Qinghai Lake in Qinghai, the weaken hydrothermal tie has led to a general decline in forage yield with generally increased temperatures and decreased precipitation.

### 4.2.3 *Inland Wetlands*

The notable impacts of climate change on wetland ecosystems are mainly reflected in wetland hydrology, biogeochemical processes, plant communities, and wetland ecological processes. In the complex hydrology environmental systems with ice, frozen soil, snow, rivers, and lakes in the Tibetan Plateau, the area change of lakes is the combined effects of climate change, water, and heat. Regional lakes in the Tibetan Plateau, Mongolia, and Xinjiang have been significantly impacted by climate change, and some wetlands and lakes have expanded under climate warming (Ding et al. 2006). The area of wetland and lakes in Sanjiang Plain in northeast China, middle north, and east part of Tibet Plateau have sharply decreased during the same period, which mainly caused by increased air temperature and decreased precipitation. For example, the area of wetland in the source reach of Yangtze River and Yellow River and Ruorgai wetland have decreased above 10 %, among which the area of alpine swamp wetland in the source reach of Yangtze River has decreased about 29 % (Wang et al. 2009).

The composition and structure of wetland vegetation have significantly changed with climate change. The lobular camphor *Carex* has expanded in range to the central area of the wetland, while deepwater communities, such as *Carex lasiocarpa*, have declined in Sanjiang Plain in northeast China. The biological diversity of the wetland has sharply declined since the 1960s. For example, species of algae have decreased by 15.5 %, while the total number of algae has increased 181.4-fold, and fish species decreased by 44.4 % between the 1960s and the early 1990s in Baiyangdian wetland. Meanwhile, the eco-environment of surrounding degrades wetland turned deterioration. Desertification in the area surrounding the wetland has expanded in north China. Such as, the desert area around Hulun wetland has expanded to more than 100 km<sup>2</sup>, and the degradation of pastures has accounted for a loss of more than 30 % of total pasture area in 1997. The wetland soil carbon pool is about 1/10–1/8 of the terrestrial soil organic carbon repository in China. The total loss over the past 50 years has probably reached 1.5 PgC.

### 4.2.4 *Biological Diversity*

Climate change and human activities have had a definite impact on biodiversity in China in the twentieth century. Some species have recently become extinct due to

climate change and human activities. For example, *Pantheratigrislecoqi*, *Equus przewalskii*, and *Saigatarica* have become extinct in desert areas in China. Green peacocks were historically present in Hunan, Hubei, Sichuan, Guangdong, Guangxi, and Yunnan. They are currently found only in western, central, and southern Yunnan Province. Przewalski's gazelle used to range across of Inner Mongolia, Qinghai, and Gansu. They are currently distributed only in the Qinghai Lake region (Ma et al. 2006).

Climate change has affected the bird phenology and distribution of animals in the Qinghai region. Spot-billed ducks in the Bohai Sea area had been summer migratory birds before the 1990s, but have now become resident birds due to winter warming. Compared with the last century, 26 species of birds, including the bean goose, gray-headed blackbird, and bald Harrier, have disappeared from the Qinghai lake.

## 4.3 Terrestrial Environment

### 4.3.1 *Land Use and Land Cover Change*

The characteristic of land use and land cover change since the 1990s includes continued decreasing in arable land and continued increasing in forest area and the dynamic stability of grassland. The land use and land cover change greatly varied in different regions. Generally speaking, land use and land cover changes are the combination result of climate change and human activities. The rising temperatures, especially the relatively large rising temperature in north China, play an important role in the northward shift of margin for Chinese paddy and dry land boundaries. 87 % of new paddy fields concentrated in the northeast region. 59 % of newly reclaimed upland farmland located in three northeastern provinces and Inner Mongolia. If the future climate in the north China remains arid, the farmland area will be further reduced, while the area of woodland and pasture will be further increased (Liu et al. 2009).

The vegetation cover index NDVI in most regions of China had experienced an increase from 1982 to 2006, indicating that vegetation activity enhanced. The pronounced increase of NDVI with greater than 1 %/10a occurred including Beijing, Tianjin and its surrounding areas, southeastern Qinghai, and middle and west part of northern Xinjiang. NDVI in most areas, south of the Yangtze River decreased with more than -1 %/10ya. NDVI in eastern coastal areas slightly declined or did not change, while western regions experienced an increasing NDVI. The overall increase of NDVI in China is closely related to climate change. The main reason of increasing of NDVI is due to extending growing season and accelerated growth. Climate change, in particular the rising temperatures and summer precipitation, may be the main driving factor for an increase in NDVI. Temperatures are the master impact factor of increase in annual maximum NDVI relative to precipitation in the northeast China. The orders of impact of temperature

on annual maximum NDVI for different types of vegetation decrease from forest, grassland, wetlands, and shrub to arable land. The projected global warming will have a significant impact on vegetation in northern China (Mao et al. 2012).

### 4.3.2 Desertification

Desertification processes are significantly affected by climate change. The relationships between typical climatic factors and land desertification are shown in Table 4.1. Increasing precipitation and the average temperature are extremely beneficial for the vegetation growth, and decreasing wind speed is also conducive to the transformation from semi-fixed sand dune to fixed dune. This is the main cause of some of the major sand-dune areas in China, such as in Horqin, and has reversed since the 1980s. Although air temperature has generally risen in the pastoral zones and sandy areas in northern China, increasing precipitation during the 10 years preceding the 1990s and a decrease of potential evapotranspiration, wind speed, and other elements have reversed the large-scale desertification in China by the start of this century.

Temperature is the most important factor affecting desertification in the Qinghai–Tibet Plateau. Desertification in the area has expanded in the past 50 years due to continued warming and permafrost degradation. The source regions of the Yangtze and Yellow Rivers in the Tibet Autonomous Region have the highest desertification rates in China. Desertification in the Qaidam Basin has also expanded (from 1961 to 2006), caused by warming climate and increasing high winds.

Climate change has exacerbated on the development of regional rocky desertification (a process of land degradation characterized by soil erosion and bedrock exposure). The impact of temperature changes is mainly through indirect effects of changes in vegetation, while precipitation intensity and precipitation amount have important direct impact on the rocky desertification. The main impacts of climate change on rocky desertification include the following: (1) Rocky desertification is increased in areas with more than 1200 mm annual precipitation in karst areas; the

**Table 4.1** Correlation coefficients between climate elements and land desertification in typical sand-dune zones (after Li et al. 2009)

|                     | Hunshandake sandy land |               |            | Horqin sandy land |               |            |
|---------------------|------------------------|---------------|------------|-------------------|---------------|------------|
|                     | Air temperature        | Precipitation | Wind speed | Air temperature   | Precipitation | Wind speed |
| Shifting sand dunes | 0.761                  | -0.751        | -0.833     | 0.684             | -0.312        | 0.71       |
| semi-fixed dunes    | -0.15                  | 0.829         | 0.324      | -0.653            | 0.679         | 0.227      |
| fixed dunes         | -0.519                 | 0.139         | 0.804      | -0.624            | 0.658         | -0.687     |

The results of Hunshandake sandy land come from the land use change from 1970 to 2000. The samples of Horqin sandy land are 31

greater the annual precipitation, the more serious the rock desertification. Annual precipitation has increased significantly in most eastern and northwestern parts of the karst areas in southwestern China, while precipitation in the middle and southwestern karst areas has significantly decreased. However, even in those regions with decreased annual precipitation, rainfall in flood season has increased, due to extreme rainstorms. Spatial patterns of precipitation are the main factors affecting the regional development of rocky desertification. Heavy rains in the karst mountain areas in southwestern China are more concentrated in the spring ( $\sim 40\%$ ) and summer (50%) seasons for the cultivation of crops in these areas. (2) Climate change has caused vegetation degradation in the karst areas. The regional NDVI for most parts of northern Guangxi and eastern and southwest Yunnan provinces has decreased, accompanied by temperature increases over the past 20 years. The decrease in annual average NDVI is more pronounced in the northern Guangxi region. There is a significant negative correlation between temperature and vegetation index. The yearly average NDVI and NPP for evergreen and deciduous broad-leaved mixed forests, which are important in karst areas, have declined markedly in the recent past, causing rocky desertification.

### **4.3.3 Soil Erosion**

Soil erosion is related to climatic conditions, the surface environment, and soil characteristics. Soil erosion in the Loess Plateau has a nonlinear relationship with annual precipitation, in that the erosion first increased and reached a peak with the increase in annual precipitation and thereafter decreased. Analysis of sediment data from 115 hydrological stations, and precipitation data from 276 rainfall stations in the Loess Plateau, suggested that the spatial and temporal variation of sediment erosion is consistent with that of precipitation changes over the past 50 years, and sediment erosion decreases with decreasing precipitation (Xin et al. 2009).

Precipitations in China have displayed distinct regional characteristics over the past 50 years. Significant climate warming and drying in the Loess Plateau has partly reduced the sediment load in rivers. However, predominant analyses indicate that water conservation contributed an average of 72.6% to the decrease in soil erosion, while decreased precipitation contributed only 27.4% in the Loess Plateau region (Xin et al. 2009). This suggests that precipitation changes caused by climate change are indeed affecting regional soil erosion. However, this effect is relatively small.

## **4.4 Agriculture and Forestry**

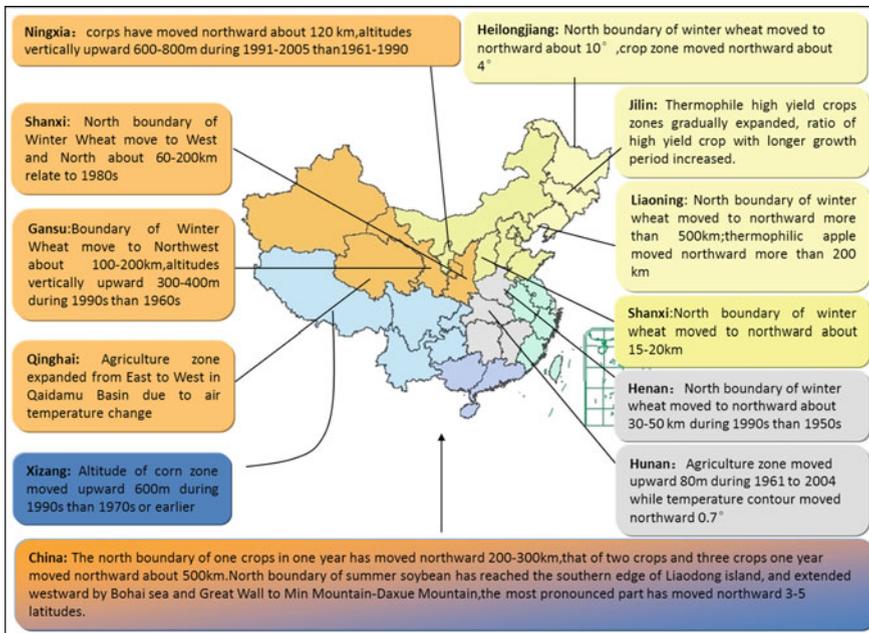
Climate change has significantly affected agriculture and forestry in China on crop growth, development, and yield formation, as well as the spatial distribution of agricultural climate resources. The general increasing of accumulated positive

temperature and the prolonged crop-growing season are benefit to expand thermophilic crops to high-latitude or alpine regions, changes of spatial distribution of different cropping system. As a result, the potential production has changed, agricultural biological and non-biological disaster has occurred more frequent, the agricultural production stability has decreased, lawn area has narrowed and moved northward, and the livestock productivity and the quality of livestock have declined. The fishery ecological environment has degraded, the traditional fishing grounds have disappeared, and fish reproductive capacity has decreased. The overall impact of climate change on structure, composition, function, productivity of high-latitude boreal forest is negative (Sun et al. 2010).

#### 4.4.1 *Agriculture*

The changes of light, heat, water resources, and other factors in agriculture climate resource have great impacts on crop yield and quality. As a result of climate change, thermophilic crop zones in China have moved northward and into higher altitudes, the growing period has been extended, and the early-maturing varieties of crops have shifted to normal-maturing or late-maturing, which improved the adjustment of crop structure and layout. The crop belt has moved northward 150–200 km and 100–200 m vertically upward in mid-latitude zone due to climate warming. The national average days of accumulated temperature greater than 10 °C will extend 15 days when the annual average temperature increases by 1 °C. The average northern boundary of the cultivation of double crops and three crops a year during 1981–2007 has moved northward compared with that during 1950–1980 with increasing temperature and accumulated positive temperature (Fig. 4.2). The largest boundary of double crops in one year moving northward is in Shaanxi, Shanxi, Hebei, Beijing, and Liaoning provinces. The largest boundary of three crops in one year moving northward is in Hunan, Hubei, Anhui, Jiangsu, and Zhejiang provinces (Yang et al. 2010).

Climate change significantly impacts on crop potential production. Reducing the number of sunshine hours and precipitation will decrease the potential production, while temperature will increase the potential production. If the light and temperature conditions are suitable, the coordination between soil moisture and light and temperature conditions will help to achieve higher crop yields. On the contrary, the crop will slowly grow, and crop potential production will decline if the crop cannot get sufficient water supply. Decreasing precipitation at this century is the major factor of Chinese crop potential production. Climate warming is caused by the increase of atmospheric CO<sub>2</sub> and other greenhouse gas concentrations. As a substrate for photosynthesis, atmospheric CO<sub>2</sub> enrichment will lead to enhanced crop photosynthesis, which will help improve crop yields. However, the carbon content in the plant increases, the nitrogen content is relatively lower, the protein may reduce, and crop quality may decline. The CO<sub>2</sub> fertilization effect is a concrete manifestation of the crop growth environment and species breed to manage conditions.



**Fig. 4.2** The changes of planting boundary of crops in past 60 years in China (after Qin et al. 2012)

Currently, research is still not completely understood by the mechanism and extent of the stimulation of  $\text{CO}_2$  on crop, and the research work in this area needs to be further strengthened.

Agricultural production in China will face three main challenges as a result of future climate warming. First, there will be an increase in agricultural production instability. Second, the geographic distribution and the structure of agricultural production will change. And third, agricultural costs will substantial increase (Ding 2003). Therefore, there is an urgent need to develop adaptation technologies and enhance China's adaptive capacity to mitigate the adverse effects of climate change and promote sustainable agricultural development.

#### 4.4.2 Animal Husbandry

Pastoral areas in China are mostly located in arid and semiarid areas, or in cold regions in high latitudes; therefore, animal husbandry is sensitive to increases in population, land use changes, and in particular, to climate change. The impacts of climate change on animal husbandry are complex. Rising air temperatures and sustained or decreasing precipitation result in an increase in evapotranspiration

of grasslands. High winds, dust storms, drought, and other extreme climate even negatively affect the growth of grass and result in a decline of pasture. More droughts strengthen the potential desertification of semiarid areas increased droughts in steppe regions, and longer droughts, which further reduce soil fertility, reduce the yield of grasslands, decrease the pasture cover, decrease the yield of forage, and decrease the grassland carrying capacity and stocking rates. On the other hand, climate warming, especially an increase in the average cold-season air temperature, favors the overwintering and reproduction of rats and other pests, leading to plant reduction and an increase in livestock epidemics. The impacts of climate change on livestock breeding both good and bad, but mainly, are adverse. Rising winter and spring temperatures and a reduction of snow-covered areas have reduced the snowstorm hazard in pastoral areas and benefited to livestock survival in winter and spring. However, higher air temperatures also lead to degradation of poultry production and an increase in mutated viral infections, which decrease livestock production.

#### **4.4.3 Fisheries**

Climate change has also impacted fisheries in China. Climate change undermines the stable structure of marine ecosystems, resulting in the destruction of ecosystems such as coral reefs, mangroves, and fish spawning grounds, which leads to a reduction of fisheries resources. Climate warming increases sea temperature, which directly affects the growth, feeding, spawning, migration, and mortality of fish. A reduction in, and disappearance of, sea ice can lead to the disappearance of spawning grounds for cold-water fish species, which inevitably affect their normal production and feeding behavior, making the endangered condition of these species worse. Climate change will lead to the fisheries population size and structure, and routes and times of fish migratory change dramatically, resulting in fisheries vanish or fisheries functions disappear.

#### **4.4.4 Forestry**

Climate change also has the important impact on forests, which is the main body of China's forestry. Climate change can affect the structure, composition, function, and productivity of forest ecosystems (especially high-latitude cold-temperature forests) and can threaten the recovery of degraded forest ecosystems. Rising temperatures in China have advanced the start of spring growth in woody plants, but there are spatial differences across the country. The start of spring has advanced in northeastern China, northern China, and the lower reaches of the Yangtze River, but it has been postponed in eastern southwest China, in the middle reaches of the Yangtze River, and in other areas. The extent of these changes across latitudes

has decreased. Measurements suggest that the spatial distribution of some types of forests has changed in response to climate change, and the tree-line elevation has risen in some areas. Climate change has negatively impacted the secondary succession in some forests, and the recovery of tropical forest ecosystems, with an increase in the mortality of trees in secondary forest successions. The intensity and frequency of droughts have caused increased forest fuel accumulation, with prolonged periods of fire danger (now beginning in the early spring), resulting more early spring and summer fire-prone forest fires, and expanded geographic distribution area of forest fires, and then intensified frequency and intensity of forest fires. Climate change is also responsible for an increase in forest pests and diseases, an expansion of their spatial distribution northward, the advance of occurrence of forest pests, the increases of the number of generations, the shorten of cycles, the increase of scope and degree of harm, and promotion of the expansion and hazards of invasive alien pests.

## **4.5 Human Habitats and Health/Infectious Disease**

### **4.5.1 Habitats**

Climate change has direct effect on habitats. About 400 million people worldwide live within 20 km of a coastline or below an altitude of 20 km. Moreover, populations in developing countries are shifting to coastal cities due to the economic advantages of the coastal areas. Global warming raises sea level, increasing the risk that heavily populated coastal lowlands will be submerged by rising water levels. China is a maritime country, the mainland coastline is about 18,000 km, and there are more than 6000 islands. The coastal areas have been China's economically developed regions. The Pearl River Delta and Yangtze River Delta regions are relatively vulnerable regions.

The effect of urban heat island effect on habitats is more and more pronounced. The urban heat island effect is a phenomenon of increased temperatures and abnormal distribution of temperatures in urban environments. Many cities in China experience the urban heat island phenomenon. For example, the temperature difference between urban and rural areas in and around Beijing, Shanghai, and Lanzhou has increased in recent decades. Moreover, the urban heat island area has expanded with increasing urban temperatures.

Studies of annual average temperatures over the past 50 years suggest that urban heat in lands raise the annual average temperature, decrease the difference between inter-annual temperatures, and contribute to climate change. The average intensity of a heat island effect in China is less than 0.06 °C, which is close to the global average of 0.05 °C. Some studies have suggested that the average intensity of the heat island effect in China has risen by 0.1 °C per 10 years from the 1970s to the 1990s, while the average intensity in the Pearl River Delta has increased from 0.1 °C in 1983 to

0.5 °C in 1993. The areal extent of heat islands in major cities has generally increased. For example, the urban heat island in Shanghai has increased from 100 km<sup>2</sup> in the 1980s to 800 km<sup>2</sup> in the 1990s. Data collected from 1961 to 2005 indicate that the temperature rose more in urban belts than in non-urban areas, by 0.28–0.44 °C per 10 years, due to the rapid urbanization in the Yangtze River Delta region between 1992 and 2003. These differences are largest in summer and slightly smaller in autumn and spring. They are smallest in winter. The heat island effect had led to a 0.072 °C increase in the average temperature of the region between 1961 and 2005 and an increase of 0.047 °C from 1991 to 2005. The annual minimum temperature increased by 0.083 °C during the period from 1991 to 2005.

Climate change and the heat island have direct or indirect impact on people's living environment through different pathways. The comfort habitat of urban residents affects their health, work, and leisure life. Climate change and the heat island effect lead to urban climate anomalies and can lead to an increase in extreme weather events, such as the frequency and intensity of lightning and heavy rain. Urban heat island effects can also cause increased fog, droughts, and wind disturbances and ultimately lead to urban meteorological disasters.

The impacts of climate change on rural living are concerned. Agriculture as main field of climate vulnerable ecosystems, any degree of climate change will have potential or significant impact on agricultural production and related processes, thus affecting the lives of rural residents. Due to the dependence on the rural agriculture, forestry, and other climate-sensitive industries, therefore, rural residents are vulnerable to climate change impacts. Moreover, many rural areas are economically constrained. The ability to adapt to climate change in rural areas is limited. Poor areas and poor people are very vulnerable to climate change and extreme weather events.

Due to climate warming, soil erosion has intensified in China, leading to the desertification in rural areas which is becoming a serious problem. Decreasing precipitation due to climate warming leads to reduction in rain-fed agriculture, thereby changing the regional farming mode.

Climate change will increase the extreme weather events, leading to the increase of the frequency and intensity of floods and droughts. Due to poor infrastructure, the rural areas have lack of capacity to deal with extreme events. Climate change exacerbates environmental problems in rural areas. The already fragile rural infrastructure cannot guarantee normal life of rural residents when facing heavy rain, flash floods, snowstorms, and other extreme weather events.

#### ***4.5.2 Life Facilities and Social Service***

An increase in the frequency and intensity of extreme weather events, such as lightning, heavy rain, and droughts, caused by climate change, leading localized flooding and road damage, traffic congestion, power outages, etc., seriously affects the normal operation of urban socioeconomic and urban infrastructure security. In

recent years, meteorological disasters such as heavy rain, lightning, fog, drought, and other threats have become the focus of urban security objects.

Climate change has a greater social impact on some services sector. Such as, the insurance industry is closely related to climate and environmental change. Increases in the frequency and intensity of extreme weather events lead by climate change have increased the amount of insurance payments, thereby increasing the risk. China is one of the countries which is most severely affected by natural disasters in the world. China's insurance market is actually facing a far more serious catastrophe risk than international insurance market due to China's sustained and rapid economic development, increasing urbanization, population, and wealth. From another perspective, climate change also has brought strong demand to the property insurance, health insurance, and other fields. Adaptation to climate change is not only a complex challenge, but also a lot of opportunities to the financial sector.

### **4.5.3 Urbanization**

Climate change affects resources and ecological environments within and around the cities, most prominently, water, thereby affecting the population carrying capacity and the development prospects cities. The direct effect of sea-level rise is flooding seawater. The salinization of groundwater has become an increasingly serious problem in many coastal cities in northern China, after continuous over-exploitation of aquifers and recent sea-level rise. Sea-level rise also leads to coastal tidal inundation. Salt tide inundation reached an unprecedented peak in the dry season of 2005/2006, posing a serious threat to the security of the water supply in cities in the Pearl River Delta. Climate changes also lead to increased hurricane intensity and bring a serious threat to coastal urban life, property and urban economy, and transportation. Because the climate of northern and northeastern China has shifted to drier and warmer conditions since the 1980s, water demand in these regions has rapidly increased, leading to a growing gap between supply and demand of water resources, and thereby seriously restricted the development of many cities in northern China.

Increasing the frequency and intensity of extreme weather events, which caused by climate change, will lead to a variety of meteorological disasters intensified, especially droughts and floods will get worse, which is profoundly affected by climate change. According to statistics, the worldwide occurrence of major meteorological disasters (such as urban flooding, heat waves, urban haze, and lightning) in the 1990s is five times more than in the 1950s. Since the daily operation of its various functions must rely on the security of lifeline systems, such as transportation, electricity, telecommunications, water, gas, sewage, and other system, urban meteorological disasters will rapidly expand and spread to wide range or even entire city once the damage on lifeline systems come up.

#### 4.5.4 Climate Change and Human Health

Global warming increases the frequency and intensity of regional heat waves, leading to an increase in heat-related injuries and diseases. As temperatures increase, fatigue, irritability, anger, and the number of accidents also increase, even the crime rate increases. Human brain tissue and myocardium are the most sensitive to high temperature with low pressure, prone to dizziness, impatient, irritability, etc., so as to cause some psychological problems (Table 4.2).

Climate change can lead to an increase in diseases in affected areas. The pathogens of many infectious diseases are sensitive to climatic conditions.

Increasing frequency and intensity of extreme events such as storms, floods, droughts, and typhoons will impact on human health through a variety of ways. These natural disasters cannot only directly cause casualties, or have indirect effects on health through damaged homes, migration, water pollution, food production (lead to hunger and malnutrition) etc., increasing the incidence of infectious diseases, but also damage the health service facilities.

Many pathogens, intermediary, the host and pathogen replication rate of infectious diseases are sensitive to climatic conditions.

The effect of climate change on waterborne diseases is complex, mainly due to socioeconomic factors that determine the supply of safe water. Extreme weather events, such as floods and droughts, probably increase the disease risk through contaminated water, poor sanitation, and other mechanisms.

The temperature and precipitation changes caused by global warming will affect the distribution pattern of diseases such as malaria and schistosomiasis. Climate change has both a direct and indirect impact on schistosomiasis transmission. When

**Table 4.2** Climate change on human health effects (after Cao et al. 2001)

| Effect on health                              | Climate change   |
|---|--|
| Diseases caused by heat wave                  | Deaths related to cardiopulmonary disease increased with high or low temperature; death and heat-related illness increase during heat waves  |
| Health effects of extreme weather and climate | Direct effects (deaths and injuries) and indirect effects (infectious disease, long-term psychological disease) of floods, landslides, landslides and storms; drought-induced disease or risk of malnutrition increase               |
| Air pollution-related mortality and morbidity | Weather affect the atmospheric concentration of pollutants; weather affecting spatial distribution, seasonal changes, and generation of airborne allergens   |
| Medium infectious disease                     | High temperatures increase development time of germs in carriers and increase the probability of the potential spread of the human body; spread of disease depends on special climatic conditions (such as temperature and humidity) |
| Skin diseases and eye diseases                | Skin cancer and the incidence of various eye diseases increase with the increase of ultraviolet B (UV-B) radiation caused by the stratospheric ozone depletion   |

air temperatures rise, such as the extreme increase in the minimum air temperature in northern China where water imported to the region as part of the WTSN project, the snails that host the parasite may migrate northward. Similarly, if global average air temperatures increase 3–5 °C in the next century, the number of malaria patients could increase by 2 times in the tropics and more than 10 times in temperate zones, due to a spread of the host mosquito.

Dengue fever is an acute infectious disease caused by dengue virus which spread primarily by *Aedes*. It mainly explodes in tropical and subtropical countries and regions. Yi et al. (2003) found that the spread of dengue is mainly affected by mosquito density. The main meteorological factors which affect mosquito density are temperature and humidity, among which the temperature is the determining factors, indicating that the temperature is the determining factor of spread of dengue fever. Chen et al. (2002) suggested that the winter (3 months) temperature in the northern region of Hainan Province is not suitable for the spread of dengue fever, while the winter temperatures in the southern region of Hainan Province may be suitable for the spread of dengue fever. The dengue fever transmission in Hainan may have a fundamental change if the average temperature of winter months increases 1–2 °C. The periods of spread of dengue fever in the northern Hainan may extend to whole year, and the spread in the southern Hainan will be at a high level, thus making it possible to transform a non-endemic dengue fever in Hainan to a regional epidemic, resulting in the potential dangers of dengue fever that may be more serious.

Climate change may also cause the extinction of some species, and the generation of new species, including viruses and bacteria. Such as in the spring of 2003, the SARS virus diseases have been an outbreak in Guangdong, Beijing, Shanxi, and other places of China and bring great harm to society and people's health and life. The SARS outbreak is related to weather conditions. It is likely to always occur in the weather with inversion atmosphere, indicating that the climatic zones with inversion atmospheric are helpful to the SARS epidemic. The avian influenza occurred in the winter and spring, with a peak in January and February, while is rare in summer and autumn.

## **4.6 Other Economic and Social Areas**

### **4.6.1 Industry**

Climate change can affect the carrying capacity and environmental capacity of many natural resources that are used by industry, and extreme weather events can disrupt some industries. A reduction of water resources negatively impacts industries such as oil refinement, chemical production, fertilizer production, electric power production, metallurgy, mining, and textile production. The significant increase of lightning can adversely affect the electronic information industry.

Climate change also affects the patterns of energy and resource consumption. Higher air temperatures result in increased demands for water, cooling technologies, health care, recreation, etc., and decreased demands for winter goods and high energy consumption for water products. In order to reduce greenhouse gas emissions, the demand for clean energy further increases, which bring the development of relevant emerging industries.

Climate change further improved the requirements on transportation infrastructure and urban infrastructure. Increasing extreme weather further increases the likelihood in the destruction of these facilities, resulting the new growth of related industries. The blizzard in early 2008 in China was an extreme weather event that covered to 20 provinces (autonomous regions), resulting in the closure of more than a dozen airports, many highways, and the Beijing–Guangzhou Railway. Weather events such as these lead to logistics problems, higher consumer prices, and the emergence of other social instabilities.

#### ***4.6.2 Energy Production and Consumption***

Energy consumption has significantly changed with climate warming. Energy consumption for cooling has increased, while energy consumption for heating in winter has decreased. Irrespective of climate change, population, per capita housing area, the increasing proportion of urban households has air conditioners inevitably increases growing residential cooling energy consumption. Studies on the energy consumption in major cities in Xinjiang Province in the past 40 years suggest that the number of days requiring heating has significantly declined, while the number of days requiring cooling has significantly increased. Climate models are predicting that the average global air temperature will rise by 1.4–5.8 °C by the end of the twenty-first century. The temperature in Xinjiang, especially the winter temperature, is projected to continue to rise. The cooling energy demand in hot season in most of the cities of Xinjiang is projected to continue increase, and heating energy demand in cold season is projected to continue to decrease.

The increase in frequency of extreme weather increases the emergency pressure on the energy system. Such as in 2008, snowstorm caused severe damage on power facilities in south China. The power outages were up to ten days in Chenzhou of Hunan Province. Meanwhile, snowstorm also led to serious losses on the communications industry. The direct economic losses of communications industry caused by the snowstorm were reported by 700 million yuan; about 14.2 million users were affected; many communications stations were affected; and 350 million yuan were invested to recover.

### **4.6.3 Tourism**

The impacts of climate change on the tourism industry mainly are on regional tourism, tourism landscape, and tourism season. In China, tourism is mainly concentrated in the eastern coastal areas of the country. The number of days in which the temperature exceeded 40° increased significantly in recent years, and low cloud cover led to strong ultraviolet radiation, resulting in marine coral resources that have been significantly affected. On the other hand, rising temperatures have caused a rise in sea level over the past 50 years (with accelerated sea-level rise in recent years), resulting in an increased risk of coastal floods in seaside areas. Climate warming will change the composition, structure, and biomass of vegetation and wildlife species in China, leading to changes in distribution pattern of forest, biodiversity damage, and changes of some of the region's natural landscape and tourism resources, thus having impact on nature reserves, scenic spots, and forest parks which are based on biodiversity and natural ecosystems.

Climate change alters tourism and outdoor recreation business season, which is the interest of tourism enterprises. For example, in other areas of the country, decreased snowfall shortened the tourist season at some winter leisure resorts and caused some losses of tourism business which operating the snow and ice of winter recreation resort project. Warming air temperature severely affected marine coral resources, degrading local tourism resources and adversely affecting on tourism industry. Extreme events, such as storms, landslides, and mudslides, will directly effect on tourist traffic safety and health of visitors and even lead to accident personal injury or death, having adverse impact on the regional tourism industry.

Extreme weather events and increases in pests and infectious diseases all contribute to a decrease in the demand for travel and tourism. Changes on natural resources, ecological environment, and people's lifestyles cause by climate change will pose a serious threat on preservation of some human non-material cultural heritage, which are sensitive and vulnerable to climate change. Meanwhile, changes in biological phenology, landscape, and population activity patterns caused by climate change will profoundly affect the overall structure and layout of tourism areas and services, which may actually bring more tourism business opportunities. Summer resort tourism, ecotourism, and water sports may increase, and ice and snow tourism areas could be moved to higher latitudes and altitudes, which would preserve tourism business opportunities.

### **4.6.4 Major Projects**

Climate change not only affects natural ecosystems and human living environment, but also has a profound impact on a large number of human constructions. Three Gorges Project, Water Transfer from South to North Project (WTSN), the Yangtze River estuary restoration project, Qinghai-Tibet railway, the Sino-Russian oil

pipeline, the Three-North Shelterbelt Project and highways, high-speed railway, the south transmission lines, and other projects are major projects and have significant impact on the development of social and economic of China. It is very necessary to assess the impact of climate change on these projects, and in particular to evaluate the impact on the safe operation of these projects', possible threats and propose adaptation measures to climate change.

Three Gorges Project, the world's largest water conservancy project, is the key backbone project of governance and development of the Yangtze River, which has benefits to flood control, power generation, navigation, etc. Affected by climate change, the rainfall-runoff relationship in Yangtze River has changed. The probability of occurrence of drought in dry season and floods in humid season has increased, and the hydrological regime changed. Meanwhile, the annual runoff and hydrological process of the upper reaches of the Yangtze River have significantly changed under the rapid growth of water consumption with the economic development, water conservancy and hydropower project construction, inter-basin water transfer, and other factors. Under future climate change scenarios, the Three Gorges reservoir area is projected to significant warming and wet, and the frequency of flood, droughts, and other extreme events of the upstream region is projected to increase. The probability of occurrence of mudslides, landslides, and other geological disasters in the Three Gorges reservoir areas may increase with the increase of heavy precipitation, which will have adverse effects on the Three Gorges Project management, dam safety, flood control, flood fighting, etc. The increasing drought in the dry season will affect the water deposition, power generation, shipping, and water environment of Three Gorges Project. Thus, the early preventive measures are very important to adapt to climate change impacts. These measures include the following: by strengthening the joint scheduling with tributaries and reservoirs in upper and middle reach, flood diversion areas in middle and downstream reach and then reducing the risk of flood and insufficient power in the dry season; implementation of watershed eco-environment management and developing a long-term plan, strengthening infrastructure construction of flood control, drought, water supply, etc.; strengthening the monitoring efforts of geological and seismic disaster; increase in reservoir sewage treatments.

WTSN is a major strategic initiative to solve the severe water shortage in northern China and also an oversize large infrastructure project which is closely related to socioeconomic sustainable development of China. Climate change has little effect on the water volume of east and middle route of WTSN. However, it probably has adversely affected on water quality of east route of WTSN. Climate change, in particular, changes in precipitation, which probably has adverse effects on water resource and ecological environment of reservoirs of the middle route of WTSN. The middle route of WTSN probably encounters frequency of flood and drought conflict between the river networks in south and north China. Climate change may lead to the risk of water shortage in the source of WTSN, no water consume demand, water pollution, floods, earthquakes and other geological disasters. At the same time, climate change will not ease the water shortage situation in north China, while the receiving water in north China will add more soil moisture,

which may lead to higher significant temperature, more latent heat and evaporation changes that may cause a certain degree of local climate change. Therefore, we need to take engineering measures and non-engineering measures to circumvent the possible project risks, hydrological risk, ecology and environmental risks, economic risks, social risks, etc. The basic starting point should be help to improve and restore the surface, ground, and coastal water environment and its associated ecosystems, while solving the short-term urgent needs of water shortages in yellow River, Huai River, and Hai River Basin. The long-term foothold of regional water issues in northern basin should focus on the basin themselves. We should ensure the necessary flow of the Yangtze River into the sea. We should coordinate inter-regional water allocation from the country's overall social, economic, and ecological interests.

The Yangtze River estuary restoration project is one of the most complex estuary management projects in the world. It is also the most ambitious water project in China. The channels, runoff into the sea, the coastal environment, and other issues caused by climate change should be assessing on focus. Climate warming led to sea-level rising, the sediment retention position of the Yangtze River estuary was traced upward, and waterway blockage was intensifying, while the impacts of storm surges, floods, heavy rain, and other extreme weather events on the Yangtze Delta restoration project become increasingly prominent. Therefore, we need to integrate measures including improving the seawall protection standards, comprehensive management on Yangtze Estuary Road, increasing coastal freshwater flow, and strengthen the Yangtze River environmental protection countermeasures.

Climate change has impacts on the Qinghai–Tibet Railway. The active layer thickness of permafrost has gradually deepened with the increasing air temperature along the Qinghai–Tibet Railway. The permafrost warming, melting, and degrading will change the stability of the basement of Qinghai–Tibet Railway. We must pay attention to the trend of future climate change along the Qinghai–Tibet Railway and the use of engineering and technical measures to adapt to the impacts of climate change. We need to build integrated management system with environment, health, safety, and transportation and to meet the needs of adaptive management.

Ecosystem degradation leads to soil and vegetation degradation, biodiversity reduction, exacerbating sand hazards, and other environmental disasters, having direct threat to West to East Gas Pipeline Project. Not only the increasing frequency of floods due to precipitation changes, but also the mountain landslides are major factors affecting the safety of the pipeline. The secondary disasters, such as ground subsidence, soil erosion, river sediment deposition, and so on, both would threaten the safe operation of gas pipeline. Strengthen the studies on the impact of climate change on project design parameters, such as ground temperature, and prevention of geological disasters are very important for engineering design, maintenance, and risk assessment.

China–Russia oil pipeline project is impacted by both the temperature changes and permafrost changes. Particularly, the underground ice melting led by climate change and anthropogenic factors, not only caused ground subsidence, but also led to the formation of secondary permafrost disasters, affects the stability of pipeline project.

We need to consider the freeze–melt disaster at the early stage, have an optimal design, and take appropriate measures to guarantee the pipeline deformation within the allowable range. Meanwhile, we need to strengthen the scientific monitoring, ensuring the stability and security operations of the gas pipeline.

Climate change has affected the vegetation distribution in “Three-North” Shelterbelt area, and the forest ecosystem structure will be changed. The single large tree species in “Three-North” Shelterbelt is expected to have more vulnerability under future climate change scenarios. Thus, there is urgent need for redrafting planning, optimal designing the structure of tree species, improving the quality of afforestation, combing with the development of the pattern of trees and shrubs with local climatic conditions, and then enhancing the ability to adapt to climate change.

Highways and high-speed rails are national transportation artery, facing with high risk of ice, snow, rain, fog, lightning, high temperature, and other inclement weather. Therefore, highways need to strengthen monitoring of meteorological information, timely adjustment of the construction and the operation plan. High-speed rails need to take measures to adapt to the impacts of climate change and focus on prevention of meteorological disasters in the key seasons and areas. South transmission line had been experienced serious loss in the 2008 snow and ice storms. Accompanied by the projected increasing in the probability of extreme weather events, south transmission lines need to strengthen prevention and protection on freezing rain, improve disaster warning, and other measures, enhancing the ability to adapt to climate change.

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