Chapter 24. Asia

Coordinating Lead Authors
Yasuaki Hijioka (Japan), Erda Lin (China), Joy Jacqueline Pereira (Malaysia)

Lead Authors
Richard Thomas Corlett (Singapore), Xuefeng Cui (China), Gregory Insarov (Russian Federation), Rodel Lasco (Philippines), Elisabet Lindgren (Sweden), Akhilesh Surjan (India)

Contributing Authors
Elena M. Aizen (USA), Vladimir B. Aizen (USA), Rawshan Ara Begum (Bangladesh), Kenshi Baba (Japan), Qingxian Gao (China), Monalisa Chatterjee (USA), Masahiro Hashizume (Japan), Manmohan Kapshe (India), Andrey G. Kostianoy (Russia), Sreeja Nair (India), Tran Van Giai Phong (Viet Nam), SVRK Prabhakar (India), Andreas Schaffer (Singapore), Rajib Shaw (Japan), Reiner Wassman (Philippines), Thomas J. Wilbanks (USA), Shaohong Wu (China)

Review Editors
Rosa Perez (Philippines), Kazuhiko Takeuchi (Japan)

Volunteer Chapter Scientist
Yuko Onishi (Japan)

Contents

Executive Summary

Warming trends and increasing temperature extremes have been observed across most of the Asian region (high confidence) [24.3]. Increasing trends in annual mean temperatures and numbers of warm days, and a decreasing trend in cold days, have been observed across most of the Asian region, including the Tibetan Plateau, during the 20th century, with the warming trend continuing into the new millennium. Annual mean precipitation trends are characterized by strong variability, with both increasing and decreasing trends observed in different parts of Asia.

Water scarcity is expected to be a major challenge for most of the region due to increased water demand and lack of good management (medium confidence) [24.4.3]. Water resources are important in Asia given the massive population. However, there is low confidence in future precipitation projections at a regional scale and thus in freshwater availability in most parts of Asia. Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources in downstream river catchments. Population growth and increasing demand arising from higher standards of living could worsen water security in many parts in Asia and affect many people in future. Better water management strategies are needed to ease water scarcity. Water saving technologies and changing to drought tolerant crops have been found to be successful adaptation options in the region.

The impacts of climate change on food production and food security in Asia will vary by region with many regions experiencing a decline in productivity (medium confidence) [24.4.4]. This is evident in the case of rice production. Most models, using a range of GCMs and SRES scenarios, show that higher temperatures will lead to lower rice yields as a result of shorter growing periods and heat-induced sterility. There are a number of regions that are already near the critical temperature threshold. However, CO_2 fertilization may at least in part offset yield losses in rice and other crops. In Central Asia, some areas could be winners (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters and slight increase in winter precipitation), while others could be losers (western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect cotton production, increase water demand for irrigation, and exacerbate desertification). In the Indo-Gangetic Plains of South Asia there could be an up to 50% decrease in the most favorable and high yielding wheat area due to heat stress at 2x CO_2. There are many potential adaptation strategies, such as crop breeding, but research on their effectiveness is limited.

Terrestrial systems are under increasing pressure from both climatic and non-climatic drivers (high confidence) [24.2.2, 24.4.2, 24.4.3]. The projected changes in climate will impact vegetation and increase permafrost degradation in Asia during the 21st Century. The largest changes are expected in cold northern and high-altitude areas, where boreal and subalpine trees will *likely* invade treeless arctic and alpine vegetation, and evergreen conifers will *likely* invade deciduous larch forest. Large changes may also occur in arid and semi-arid areas, but uncertainties in precipitation projections make these difficult to predict. Vegetation change in the more densely populated parts of Asia will be constrained by the impact of vegetation fragmentation on seed dispersal. The impacts of projected climate changes on the vegetation of the lowland tropics are currently poorly understood. Trends in phenological timing consistent with the impacts of regional warming are widespread in eastern Asia, particularly for plants. Permafrost degradation will spread during the 21st century from the southern and low-altitude margins, advancing northwards and upwards [24.4.2.3]. Many models agree on the direction of change, but rates of change vary greatly between different projections. The Altai-Sayan, Pamir and Tien Shan glaciers have lost on average 10% of their area and 15% of their ice volume since 1960. Rates of further glacier degradation depend mainly on increases in summer air temperature and changes in precipitation [24.9.3].

Coastal and marine systems in Asia are also under increasing pressure from both climatic and non-climatic drivers (high confidence) [24.4.3]. It is very *likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels and in the Asian Arctic there is *high agreement* and *medium evidence* that rising sea-levels will interact with projected changes in permafrost and the length of the ice-free season to cause increased rates of coastal erosion. Coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea-levels**.** Widespread damage to coral reefs correlated with episodes of high sea-surface temperature has been reported in recent decades and there is *high confidence* that such damage will increase during the 21st century as a result of both warming and ocean acidification.

Multiple stresses caused by rapid urbanization, industrialization and economic development will be compounded by climate change (high confidence) [24.4, 24.5, 24.6, 24.7]. Climate change is expected to adversely affect the sustainable development capabilities of most Asian developing countries by aggravating pressures on natural resources and the environment. Development of sustainable cities in Asia with fewer fossil fuel driven vehicles and with more trees and greenery would have a number of co-benefits including public health.

Extreme events will have greater impact on human health, security, livelihood, and poverty sectors with different magnitude and types in Asia (high confidence) [24.4.6]. More frequent and intense heat-waves in Asia will increase mortality and morbidity in vulnerable groups. Increases in heavy rain and temperature will increase the risk of diarrheal diseases and malaria. Increases in flood and drought will exacerbate rural poverty in parts of Asia due to negative impacts on rice crop and increases in food prices and the cost of living.

There are regions within Asia that are not sufficiently represented in studies of observed climate change, in particular Central and West Asia [24.8]. Numerical data on trends in precipitation is hard to find compared to trends in temperature. Furthermore, research data on changes in extreme climate events does not cover most Asian regions. Studies of both observed and projected impacts on biodiversity, boreal forest dynamics, CO_2 fertilization of crops and plants, and urban settlements are limited. More trans-disciplinary research is needed on direct and indirect health effects from climate change impacts on air and water quality and water quantity in different parts of Asia. The vulnerability, impacts and adaptation of aggregated household welfare, livelihoods and poverty need to be adequately studied.

24.1. Introduction

Asia is defined here as the land and territories of 51 countries/regions (see Figure 24-1). It can be broadly divided into six sub-regions based on geographical position and coastal peripheries (see Table 24-1). These are (in alphabetical order) Central Asia (5 countries), East Asia (7 countries/regions), North Asia (2 countries), South Asia (8 countries), Southeast Asia (12 countries) and West Asia (17 countries). Asia has a diversity of social, cultural and economic characteristics. The population of Asia in 2011 was reported to be about 4,207 million, which is about 60% of the world population (UN, 2011). The population density is about 134 per square kilometer (PRB, 2012). The highest life expectancy at birth is 83 (Japan) and the lowest is 49 (Afghanistan). In 2009, the GDP per capita ranged from US$ 543 (Afghanistan) to US$ 45,903 (Japan) (World Bank, 2013). Almost half of the population in Asia lives below the poverty line, where their income is below US$ 1.25 per day by 2005 prices (World Bank, 2013).

[INSERT FIGURE 24-1 HERE
Figure 24-1: The land and territories of 51 countries/regions.]

[INSERT TABLE 24-1 HERE
Table 24-1: The 51 countries/regions in the six sub-regions of Asia.]

24.2. Major Conclusions from Previous Assessments

24.2.1. Climate Change Impacts

Climate change, variability and extreme events

Observed. Warming is strongest over the continental interiors of Asia, and warming in the period 1979 onwards was strongest over China in winter and eastern Asia in spring and autumn. [WG1 AR4 3.2.2.7]. From 1900 to 2005, precipitation increased significantly in northern and central Asia but declined in parts of southern Asia [WGI AR4 SPM]. A warming trend in daily temperature extremes was observed for much of Asia (medium confidence) [SREX 3.3.1]. No systematic spatially coherent trends in heavy precipitation have been found in most of Asia, except for a weak increase in the frequency of extreme precipitation that was observed in northern Mongolia (low to medium confidence) [SREX 3.3.2]. However, both positive and negative statistically significant trends have been found at sub-regional scales throughout Asia (low to medium confidence) [SREX 3.3.2]. A decreasing trend was observed in rainfall in the South Asian and East Asian monsoons, due to a rise in sea-surface temperature [SREX 3.4.1]. Coastal areas of Asia have reported that sea level rise has accelerated relative to the long-term average and is greater than the global average [WG2 AR4 10.3.1].

Future projections. Future projections show that warming will be least rapid in Southeast Asia, stronger over South Asia and East Asia, and greatest in the continental interior, with the most pronounced warming at high latitudes in North Asia [WG2 AR4 10.3.1]. Annual precipitation projections indicate an increase in most of Asia during this century [WG2 AR4 10.3.1]. An increase in heat waves is also projected for South Asia, East Asia, and Southeast Asia [WG2 AR4 10.3.1]. Future projections suggest that heavy precipitation will increase in West and South Asia, as well as the Asian monsoon region, notably in Bangladesh and in the Yangtze river basin [SREX 3.3.2], while projection results for the South Asian monsoon precipitation point to both increases and decreases in precipitation (low confidence) [SREX 3.4.1].

Climate change impacts

Observation. Changes in drought patterns have been reported for the monsoon regions of Asia with variations at the decadal time scale (low confidence) [SREX 3.5.1]. Studies in East Asia show increasing dryness in the second half of the 20th century (medium confidence) [SREX 3.5.1]. Flood observation results show that there is an upward trend in the annual flood maxima of the lower Yangtze, increasing likelihood for extreme floods in the Mekong river, and both upward and downward trends in four selected river basins of the northwestern Himalaya (low confidence) [SREX 3.5.2].

Projections. Global and regional studies project a higher likelihood of hydrological drought by the end of the century, with a substantial increase in the number of drought days in southern Asia from Indochina to southern China, while increases in drought are projected for inland China and central Eurasia [SREX 3.5.1]. Projections point to an increase in the risk of floods in most humid Asian monsoon regions (low confidence) [SREX 3.5.2].

24.2.2. Vulnerabilities and Adaptive Strategies

Vulnerable sectors. Crop yields in the past few decades have declined in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of El Niño events and reductions in the number of rainy days (medium confidence) [WG2 AR4 10.2.4.1]. Studies suggest that in the future as well substantial decreases are probable, not only in cereal production potential (medium confidence) [WG2 AR4 10.ES], but also in the production of livestock, fisheries, and aquaculture [WG2 AR4 10.4.1.1; WG2 AR4 10.4.1.3]. Most projections suggest that increasing urbanization and population in Asia could result in increased food demand and reduced food supply due to limited availability of cropland area and yield declines [WG2 AR4 10.4.1.4]. Food insecurity and loss of livelihood would be further exacerbated by the loss of cultivated land and nursery areas for fisheries by inundation and coastal erosion in tropical Asia [WG2 AR4 10.4.1.4]. Changes in the hydrological cycle with corresponding changes in the water resources have been observed, with a noticeable regional variability, in all of Asia [WG2 AR4 10.2.4.2]. One of the most pressing environmental problems in South and Southeast Asia will be the expansion of areas under severe water stress as the number of people living under severe water stress is projected to increase substantially in absolute terms [WG2 AR4 10.4.2.3]. Oceanic, coastal, and other natural ecosystems have suffered degradation as a result of global warming, sea-level rise and changes in intensity and amount of precipitation [WG2 AR4 10.2.4.3; WG2 AR4 10.2.4.4]. Projections show that all coastal areas in Asia are facing an increasing range of stresses and shocks, the scale of which now pose a threat to the resilience of both human and environmental coastal systems, and could be additionally exacerbated by climate change [WG2 AR4 10.4.3.1]. Many plant and animal species are at risk of becoming extinct as a consequence of the combined effects of climate change and habitat fragmentation (medium confidence) [WG2 AR4 10.ES; WG2 AR4 10.2.4.5]. Central, East, South and Southeast Asia reported deaths and disorders from heat waves and outbreaks of infectious diseases linked to rising temperatures and rainfall variability, particularly in low-income areas with poor water and sanitation safety (medium confidence) [WG2 AR4 10.ES; WG2 AR4 10.2.4.6]. Substantial direct impacts on public health and livelihood can be expected also in the future due to possible increases in climate change related diseases, as well as heat stress [WG2 AR4 10.4.5]. Climate change is also expected to adversely affect the sustainable development capabilities of most Asian developing countries by aggravating pressure on natural resources and the environment, in addition to factors such as rapid urbanization, industrialization and economic development (high confidence) [WG2 AR4 10.ES ; WG2 AR4 10.7].

Vulnerable areas. Regions of South and Southeast Asia were reported as vulnerable to climate change, due to the exposure of their population to severe water stress [WG2 AR4 10.4.2.3]. Furthermore, the same regions are expected to experience higher endemic morbidity and mortality due to diarrheal disease related to climate change (high confidence) [WG2 AR4 10.ES; WG2 AR4, 10.4.5]. Increases in coastal water temperature would exacerbate the risk of cholera in South Asia (high confidence) [WG2 AR4 10.ES; WG2 AR4 10.4.5]. Crop yields in South and West Asia could decrease by a third by the middle of this century (medium confidence) [WG2 AR4 10.ES; WG2 AR4 10.4.1.1]. Glaciers on the Tibetan Plateau are projected to shrink at an accelerated pace, thus possibly increasing the number and intensity of glacial melt-related floods and leading to slope destabilization and a decrease in river flows as glaciers recede (medium confidence) [WG2 AR4 10.ES; WG2 AR4 10.4.2.1; WG2 AR4 10.2.4.2]. Projected sea-level rise would result in significant losses of coastal ecosystems, along with increased risk of flooding on the coasts of South and Southeast Asia (high confidence) [WG2 AR4 10.ES; WG2 AR4 10.4.3.1]. Sea-level rise and declining river runoff, coupled with extreme events such as flooding and intensifying storm surges, would have adverse impacts on human settlements, aquaculture industry and infrastructure of Asia's densely populated megadeltas (high confidence) [WG2 AR4 10.4.3.2; SREX 4.4.3]. Stability of wetlands, mangroves and coral reefs around Asia is likely to be increasingly threatened (high confidence) [WG2 AR4 10.ES; WG2 AR4 10.4.3.2; WG2 AR4, 10.6.1].

Adaptive strategies. Adaptive strategies for the agricultural sector that have been identified in AR4 are intended to increase adaptive capacity by modifying farming practices, improving crops and livestock through breeding, investing in new technologies and infrastructure, and making changes in management philosophy through education and the provision of climate change-related information [WG2 AR4 10.5.1]. In the water sector, dealing with water use inefficiency and the promotion of recycled water were found useful in many agricultural areas in Asia [WG2 AR4 10.5.2]. Along the coast, protection, such as dike heightening and strengthening, is considered to be important in responding to sea-level rise [WG2 AR4 10.5.3]. Most forests in Asia would benefit from comprehensive inter-sectoral programs that combine measures to control deforestation and forest degradation [WG2 AR4 10.5.4].

Implementation of monitoring and warning systems would be helpful in reducing the impacts of climate change on human health [WG2 AR4 10.5.5]. Effective adaptation and adaptive capacity in Asia, particularly in developing countries, will continue to be limited by several ecological, social and economic, technical and political constraints [WG2 AR4 10.5.7]. These constraints also include alterations of the physical environment, as well as the adaptive capacities of some ecosystems, spatial and temporal uncertainties associated with forecasts of regional climate, limited national capacities in climate monitoring and forecasting, and lack of coordination in the formulation of responses [WG2 AR4 10.5.7]. Countries of Asia facing serious domestic conflicts, pervasive poverty, hunger, epidemics, terrorism and other urgent and pressing concerns may not view climate change and the need to implement adaptation as immediate priorities [WG2 AR4 10.5.7]. Slow changes in the political and institutional landscape, and in the existing legal and institutional framework, remain inadequate to facilitate implementation of comprehensive and integrated responses to climate change [WG2 AR4 10.5.7]. In order to address such constraints the following measures would be of use: improving access to high-quality information about the impacts of climate change; adaptation and vulnerability assessment by setting in place early warning systems and information distribution systems to enhance disaster preparedness; reducing the vulnerability of livelihoods and infrastructure to climate change; promoting good governance, including responsible policy and decision making; empowering communities and other local stakeholders so that they participate actively in vulnerability assessment and implementation of adaptation; and mainstreaming climate change into development planning at all scales, levels and sectors [WG2 AR4 10.5.7].

_____ START BOX 24-1 HERE _____

Box 24-1. What's New on Asia in AR5?

- Improved country coverage on observed and future impacts of climate change
- Increase in number of studies reflecting advances in assessment tools (e.g. more use of remote sensing and modelling of impacts); with an evaluation of detection and attribution where feasible.
- More conclusions now have confidence statements, while confidence levels have changed in both directions since AR4.
- Expanded coverage of issues; for example discussion on the Himalayas has been expanded to cover observed and projected changes as well as impacts [Box 3-2] including on tourism [10.6.2]; livelihood assets such as water and food [9.3.3.1; 13.3.1.1; 18.5.3; 19.6.3]; poverty [13.3.2.3.]; cultural erosion [12.3.2]; flood risks [18.3.1.1; 24.2.1]; health risks [24.4.1.2; 24.4.6.2] and forest distribution [24.4.2.2].

_____ END BOX 24-1 HERE _____

24.3. Observed and Projected Change

24.3.1. Observed Climate Trends and Variability

Temperature. In accordance with the findings of AR4, increasing trends in annual mean temperature at the country scale have been observed across most of the Asian region, including the Tibetan Plateau, during the 20th century, with the warming trend continuing into the new millennium (see Table 24-2). The contribution of the urban heat island effect to the temperature increase have also been pointed out (Fujibe, 2011; Ren, 2008). Despite a limited amount of information, a stronger upward trend is observed for winter mean temperatures, as compared to the summer means in East Asia, as well as in Bangladesh, Nepal, and over eastern Khengay and across the Khentey Mountains, Mongolia (Kim and Roh, 2010; Khattak *et al.*, 2011, Schaefer and Domroes, 2009; Shahid, 2010). On the other hand, decreasing trends were observed for the summer diurnal temperature range in the northwestern part of Kashmir, India (Roy and Balling, 2005), and for the mean minimum temperature in Karachi, Pakistan (Sajjad *et al.*, 2009).

[INSERT TABLE 24-2 HERE
Table 24-2: Summary of key observed past and present annual mean temperature trends in Asian countries/regions.]

Precipitation. Annual mean precipitation trends are characterized by strong variability, with both increasing and decreasing trends observed throughout Asia (see Table 24-3). In India, Japan, and Kazakhstan no clear national trend was observed, although on a subnational level both positive and negative trends were observed. Total summer precipitation shows an increasing trend in Southeast and Northwest China and a decreasing trend in Central China (Yao *et al.*, 2008).

[INSERT TABLE 24-3 HERE
Table 24-3: Summary of key observed past and present annual mean precipitation trends in Asian countries/regions.]

24.3.2. Observed Changes in Extreme Climate Events

As summarized in 24.2.1, based on SREX, trends of extreme events have been observed throughout Asia and additional events have been recorded.

Temperature extremes. Warm days and nights are significantly increasing in such regions as West Asia, South Asia, Southeast Asian coasts and Northeastern Siberia. They are, in contrast, significantly decreasing in regions including Mongolia, North China, Afghanistan and Pakistan, and Malaysia (Fang *et al.*, 2008). Extreme warm-month events have strong spatial dependence, with smaller variability over the Tibetan Plateau, the North China plain and coastal areas of South China, and larger variability over North China (Wan, 2009).

Heat waves. Trends in heat waves displayed noticeable regional variability. Regional wet heat waves are more frequent and intense in China (Ding and Qian, 2011).

Heavy precipitation. Regionally and sub-regionally varying trends have been observed in heavy precipitation over the Asian continent. The western part of Russia shows increases in heavy precipitation considerably with exceeding areas of decrease, in eastern part, speeds of the increase in heavy precipitation are lower and those of decrease, higher, than in Western part (Bogdanova *et al.*, 2010). Heavy precipitation has mainly increased in West Japan and in autumn, although weak positive trends have been found in most other regions and seasons (Fujibe *et al.*, 2006; Fujibe, 2008). The frequency of extreme rainfall has increased in Southeast China (Yao *et al.*, 2008) and the frequency and intensity have increased in Korea (Im *et al.*, 2008; Ho *et al.*, 2003; Im *et al.*, 2011). The intensity of extreme wet days has increased and the frequency of extreme wet days significant decreased in some parts of Peninsular Malaysia (Zin *et al.*, 2010). Variability in the frequency and intensity of extreme rainfall during the monsoon season has been observed in India (Goswami *et al.*, 2006; Rajeevan *et al.*, 2008)

Dryness. Spatially varying trends in dryness, indicated by different measures (Consecutive Dry Days, Soil Moisture Anomalies, Palmer-Drought Severity Index) were observed within most Asian regions. Soil moisture droughts have become more severe, prolonged, and frequent during the past 57 years in China, especially northeastern and central China (Wang *et al.*, 2011a)

Cyclones. Typhoon influence has increased in subtropical East Asia and considerably decreased over the South China Sea due to changes in the large-scale steering flow (tropospheric cooling in the last 20 years was suggested as cause) (Wu *et al.*, 2005). Tropical cyclone frequency shows a decreasing trend over most parts of China, except at some locations in the low reaches of the Yangtze River (Ying *et al.*, 2011). Duration of the most extreme winds, including tropical storms and typhoons, has been growing over Southeast Asian seas, mainly the South China Sea and the Philippine Sea (Rozynski *et al.*, 2009). Frequency of typhoon passage has decreased significantly in the East China Sea and Philippine Sea in the 1980-2001 periods, relative to 1951-1979, and a continuous downward trend over the Philippine Sea has been observed. (Ho *et al.*, 2004). Tropical cyclone frequency has decreased in the northwestern Pacific, while in the southeastern Pacific it increased until the early 1990s and then decreased moderately (Chen, 2009).

24.3.3. Socio-Economic Scenarios for Climate Modeling and Assessment of Impacts, Adaptation and Vulnerabilities

In the process of assessing climate change for the purposes of AR5, scenarios called Representative Concentration Pathways (RCPs) were developed, in which a wider range of potential future radiative forcing pathways were presented. Subsequently, socio-economic and climate scenarios have been developed in parallel by utilizing the RCPs [WG2 AR5 FOD 1.1.3; WG3 AR5 FOD 6.1.3]. The purpose of developing the four RCP scenarios was to compare climate change, climate change impacts, and emission pathways under different stabilization targets (Moss *et al.*, 2010). Shared Socio-economic Pathways (SSPs) and Shared Climate Policy Assumptions (SPAs) have also been developed to provide scenario elements such as Economic Growth, Globalization, Distribution/ Equity, Environmental Ethics and Values, Institutions and Governance, Technological Change and Access, and Population and Demographics (Kriegler *et al.*, 2012; van Vuuren *et al.*, 2012). SSPs and SPAs are essential for assessment of impacts, adaptation and vulnerabilities (IAVs) because Asian countries have a huge variety of current socio-economic conditions [24.1] and their future socio-economic situation could be varied under scenario assumptions. Many Asia-specific research projects have been conducted for assessing future socio-economic conditions in connection with the achievement of a low-carbon society under the constraints of climate change stabilization (e.g. Winyuchakrit *et al*., 2011; Akashi *et al*., 2012; Shukla *et al*., 2010). On the other hands, few IAV research studies including or focusing on Asia have been reported in which IAVs are discussed in relation to differences in climate change and future socio-economic conditions (Hasegawa *et al*., submitted)

24.3.4. Projected Climate Change

The projected changes for temperature and precipitation in Asia are summarized based on AR5 WG1 SOD (see Table 24-4 and Figure 24-2).

[INSERT TABLE 24-4 HERE
Table 24-4: Summary of projected changes for a variety of climate parameters [WG1 AR5 SOD Ch. 14.]

[INSERT FIGURE 24-2 HERE
Figure 24-2: Change in annual temperature and precipitation in Asia.]

24.4. Observed and Projected Impacts, Vulnerabilities, and Adaptation

The key obserced and future climate change impacts in Asia are summarized based on sub-section from 24.4.1 to 24.4.6 (see Tables 24-5 and 24-6).

[INSERT TABLE 24-5 HERE
Table 24-5: Summary of key observed past and present climate change impacts in Asia.]

[INSERT TABLE 24-6 HERE
Table 24-6: Summary of key future climate change impacts in Asia.]

24.4.1 Freshwater Resources

24.4.1.1. Sub-Regional Diversity

The water sector in Asia is significantly vulnerable to shifts in climate due to the dependence of its huge agricultural sector on precipitation, river runoff, and groundwater (see Table 24-5). Hence, adequate water supply is one of the major challenges in Asia, particularly Central Asia (Vorosmarty *et al*., 2010). Regional assessments of the environmental impact of the freshwater situation are greatly needed (Pfister *et al*., 2009). Growing demand for water is driven by soaring population, increasing urbanization, and thriving economic growth. Arid countries of the Middle East and Central Asia face major challenges in ensuring a freshwater supply, which will continue to decline with the decrease in precipitation, groundwater recharge and surface runoff (Kitoh *et al*., 2008). Mismanagement of water resources is increasing tension among five Central Asian states of the former Soviet Union – Kazakhstan, Kyrgyzstan, Turkmenistan, Uzbekistan, and Tajikistan (Lioubimtseva and Henebry, 2009; Siegfried *et al*., 2010).

24.4.1.2. Observed Impacts

Water availability has varied in most river catchments in China during the past several decades, detected with high confidence, but this can be attributed with low confidence to climate change rather than other human activities (see Table 24-5). No evidence shows significant changes in the Kherlen River Basin in Mongolia (Brutsaert and Sugita, 2008). The surface water resources of Central Asia are primarily generated in mountain glaciers. Increased runoff from shrinkage of glaciers has been observed in the Himalayas (Zhang *et al*., 2011; case study box in Ch.3; case study 24.9.3) and Central Asian mountains due to increased temperature (high confidence in detection and attribution, Casassa, G., P. Lopez, *et al*., 2009; Shrestha and Aryal, 2011). Apart from water availability, climate change is correlated with surface water quality (medium confidence in detection and attribution, Prathumratana *et al*., 2008; Delpla *et al*., 2009; Huang *et al*., 2009 ; Park *et al*., 2010; Zhang *et al*., 2007), which may increase health risk (Tornqvist *et al*., 2011). It is also noticeable that groundwater quality is also related to climate change (Thakur and Ojha, 2010; Winkel *et al*., 2011; Fendorf *et al*., 2010; Gunawardhana and Kazama 2012). It has been suggested that the water crisis in Asian countries is partly caused by poor management (Biswas and Seetharam, 2008).

24.4.1.3. Projected Impacts

Projected impacts of future climate change (A1B scenario with 5 GCMs) on water availability in Asia, considering the future demand, differ substantially among river basins (Immerzeel *et al*., 2010). The water demand in most Asian countries is gradually increasing because of increases in population, irrigated agriculture (Lal, 2011) and growth in the industrial sectors. Tropical Asia will experience severe dry and wet spells that will reduce water supply reliability and increase chances of flooding. Even though precipitation in northern and temperate Asia is expected to increase overall (Park *et al*., 2010), socio-economic development will pose a challenge to freshwater resources. Projections (A2 scenario with multiple GCMs) suggest that throughout much of Russia a warmer climate would decrease water availability due to the increase in evaporation, but on the other hand precipitation would increase which tends to increase water availability (Alcamo *et al.,* 2007). In China, a projection (A2, PRECIS) suggests that there will be insufficient water for agriculture in the 2020s and 2040s due to the increases in water demand for non-agricultural uses, although positive trends in precipitation may occur in some areas (Xiong *et al*., 2010). In a study of the Mahanadi River Basin in India, the future water availability projection (A2, CGCM2) indicated an escalating trend in excess river runoff (runoff after meeting water demand), thereby increasing the future possibility of floods for the month of September, yet the outcomes for April indicate an accelerating water scarcity (Asokan and Dutta, 2008). In the Ganges, effects of climate change could become large enough to offset the large increases in demand in a +4ºC world, due to a projected large increase in rainfall (2ºC and 4ºC temperature increase from ensemble GCMs; Fung *et al*., 2011). Given the already very high level of water stress in many parts of Central Asia, projected temperature increases and precipitation decreases (SRES scenarios from IPCC AR4 23 models) in the western part of Kazakhstan, Uzbekistan, and Turkmenistan could exacerbate the problems of water shortage and distribution (Lioubimtseva and Henebry, 2009). Considering the dependence of Uzbekistan's economy on its irrigated agriculture, which is consuming more than 90% of the available water resources of the Amu Darya basin, climate change related impacts on river flows would also strongly affect the economy (Schlüter *et al*., 2010). Fresh water resources in coastal areas might be reduced over the next century in Asia, except for Southeast Asia, with the vulnerable areas including South India, the Bangladesh region and China (A2 scenario, HadCM3; Ranjan *et al*., 2009).

24.4.1.4. Vulnerabilities to Key Drivers

It is suggested that river discharge will be influenced by rainfall change and rapid melting of snow and frozen soil in the river catchment (Tachibana *et al*., 2008) associated with climate change (Jian *et al*., 2009). Snowfall and snow melting is estimated to be very sensitive to climate warming because the surface air temperatures in heavy snow regions in Monsoon Asia are near 0°C even during winter. The seasonal cycle of river runoff would be modified and affect water management in heavy snow regions in Asia (Ma *et al*., 2010; Im *et al*., 2010; Sato *et al*., 2012; Yamanaka *et al*., 2012). Water management in river basins needs to be coordinated among countries, for example water management in the Syr Darya river basin relates to Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan, Kazakhstan (Siegfried *et al*., 2010).

24.4.1.5. Adaptation Options

Asia is by far the largest user of irrigation water in terms of volume. During the second half of the 20th century, Asia has built many reservoirs and almost tripled its surface water withdrawals for irrigation. Reservoirs partly mitigate the seasonal differences and increase water availability for irrigation (Tyler and Fajber, 2009; Biemans *et al*., 2011). However, they might not be able to continue the same supply because of a change in reservoir inflow due to the effects of climate and socioeconomic change. To adapt to the climate change impacts on water resources, many Asian countries apply water saving technologies in irrigation (Ngoundo *et al*., 2007; Tischbein etal., 2011) and other consumptive purposes (Fleskens *et al*., 2007), change to more drought-tolerant crops (Thomas, 2008; Zhao *et al*., 2010), increase water supply (Sadoff and Muller, 2009), and improve management (Kranz *et al*., 2010). In monsoonal Asia, development of water control systems has contributed to improved rice harvests (Hatcho *et al*., 2010).

Four strategies (a new flood map, an early warning system, a relief program, and more community education) have been developed in the Sarawak River system in Malaysia to reduce the excessive flood loss (Mah *et al*., 2011). Hazard mapping could help both decision-makers and local communities to understand the current situation and, through this, it would be possible to anticipate or assess the flexibility to adapt to future changes through proper planning and technical design. Examples include mapping in the Himalayan region (Eriksson *et al*., 2009), risk mapping of slope failure in Japan (Ono *et al*., 2011) and proposed investments in river regulation and storage in Nepal to control floods and to augment low-season flows in India and Bangladesh in the Ganges River Basin (Sadoff and Muller, 2009).

The equitable sharing of water and the drought-proofing of rural livelihoods will require an increasing physical capacity to store water (van der Zaag and Gupta, 2008). Moreover, policy processes in the current water management regime are strongly shaped by informal institutions and the lack of enforcement of formal regulations. The high degree of centralization of the management regime (Webster and McElwee, 2009) and the lack of vertical integration are possible explanations for the rather low adaptive capacity (Schlüter *et al*., 2010). Legal aspects of water management also need to be considered in South Aisa (Uprety and Salman, 2011; D'Agostino and Sovacool, 2011).

24.4.2. Terrestrial and Inland Water Systems

24.4.2.1. Sub-Regional Diversity

Asia supports examples of all the major natural terrestrial ecosystem types, with the predominant types differing between sub-regions. North Asia is a region of tundra, boreal forests and grasslands, Central and West Asia are dominated by desert and semi-desert ecosystems, and the Tibetan Plateau is covered in a variety of largely treeless alpine ecosystems. These four sub-regions have relatively low human population densities in most areas, except for parts of Central and West Asia, and are still largely covered in natural ecosystems, although some of these have been extensively modified. In the three remaining sub-regions, in contrast, natural ecosystems have been completely replaced over large areas by human-dominated landscapes. The major natural ecosystems of East Asia included temperate deciduous and subtropical evergreen forests, giving way to boreal forest in the northeast and to grasslands and deserts in the west. South Asia and Southeast Asia were largely covered in tropical forests, with deciduous and semi-evergreen forests most extensive in South Asia and evergreen rain forests more important in Southeast Asia. South Asia also has extensive semi-desert areas in the west and northwest, and a variety of alpine ecosystems in the north, while Southeast Asia supports a small area of alpine vegetation and ice above the treeline in New Guinea. Asia includes several of the world's largest river systems (Indus, Ganga-Brahmaputra-Meghna, Irrawaddy, Mekong, Pearl [Zhu Jiang], Yangtze [Chang Jiang], Yellow [Huang He], Amur, Lena, Yenisei, Ob, Mamberamo, Fly, Sepik) with their associated deltas, as well as the world's deepest freshwater lake, Lake Baikal, the semi-saline Caspian Sea, and the saline and now greatly shrunken Aral Sea.

24.4.2.2. Observed Impacts

Temperatures have shown a largely consistent rise across Asia since 1970, but changes in precipitation have been complex and varied [WG1 AR5 SOD Ch. 14]. In general, observations of biological changes in terrestrial ecosystems consistent with the impacts of climate change are more common in the cold and/or arid north and west of the region, and at high altitudes, where rising temperature and, in some areas, increasing precipitation have relaxed constraints on the growth of plants and the distributions of both plants and animals. In contrast, there have been very few reports from the tropical lowlands of impacts and none that can be linked to recent climate change with high confidence. Many changes in inland water systems have also been reported, but the impacts of climate change have been difficult to disentangle from natural variability and a wide variety of other, concurrent, human impacts (Bates *et al.*, 2008; Wang *et al.*, 2011b; Zheng, 2011).

Phenology and growth rates. The most widely reported impacts attributed to the observed climate trends have been changes in the timing of life-history events in plants and animals. Combining information from species-level observations of plants, satellite measurements of ‘greenness’ (Normalized Difference Vegetation Index, NDVI) and modeling, Ma and Zhou (2012) conclude that plant growth in China has started on average 2.9 days per decade earlier since the early 1980s and that this is *likely* a response to spring warming. The shift was largest in forests and smallest in grasslands and shrublands, where changes in precipitation may be more important. Regional studies in northern and eastern China, and in Japan, using observational or satellite data, have shown similar general trends, with earlier greening in spring, delayed senescence in autumn, and thus a longer growing season, associated with rising temperatures, although the details vary between sites and species (Doi and Katano, 2008; Bai *et al.*, 2010; Guo *et al.*, 2010; Li and Zhou, 2010; Yu *et al.*, 2010; Cai *et al.*, 2012; Chen and Xu, 2012; Dai *et al.*, 2013; Ogawa-Onishi and Berry, 2013). Earlier spring flowering associated with rising temperatures has also been recorded for a variety of tree species across temperate China and Japan (Doi, 2007; Doi and Katano, 2008; Wu *et al.*, 2009; Bai *et al.*, 2010; Fan *et al.*, 2010; Fujisawa and Kobayashi, 2010; Ge *et al.*, 2011; Dai *et al.*., 2013), with cherry trees in Kyoto now flowering earlier than they have at any time in the previous 1200 years (Primack *et al.*, 2009). In temperate East Asia, these changes in plant phenology have been detected with high confidence and can be attributed to climate change with medium confidence. Changes in animal phenology have also been reported from China, Japan and South Korea, but their direction varies between species and locations, and the relationship with climate change is often unclear (Kusano and Inoue, 2008; Lee *et al.*, 2011; Kobori *et al.*, 2012; Ogawa-Onishi and Berry, 2013).

In the boreal forests of northern Asia, satellite data, validated with ground observations, shows a trend to earlier greening from 1982 to the 1990s, which is strongest in Central Siberia, followed by a slight delay in many areas (Delbart *et al.*, 2008). On a continental scale, boreal forest leafing advanced by 3.9 days per decade for 1982-1999 and was earlier in the mid-1990s in Central Siberia than at any time since 1920. A general trend to earlier spring green-up from 1982 to 2006 is also evident from satellite NDVI data for the Hindu-Kush-Himalayan region, from Afghanistan to Myanmar, with the strongest temporal trends in the west (Panday and Ghimire, 2012). A more detailed study of the Himalayas over the same period found that the growing season had advanced by an average of 1.9 days per decade, with no change at the end of the season, in apparent response to a mean warming of 1.5 ºC (Shrestha *et al.*, 2012). There was a great deal of spatial heterogeneity, with areas in the drier western Himalayas more likely to have negative correlations with spring temperatures and a positive response to rainfall. In the Trans-Himalayan region of Nepal, wetter areas followed regional trends, but semi-arid areas had a delayed and shortened growing season from 2000 to 2009, as a result of a decline and delay in snow cover (Paudel and Andersen, 2012). Patterns were heterogeneous for 1981-2008 in Central Asia, where temperatures are generally increasing and precipitation decreasing (Kariyeva *et al.*, 2012). NDVI data showed an earlier start to the growing season in much of the region, but a substantially later start in desert and semi-desert areas in Turkmenistan and southern Uzbekistan. On the Tibetan Plateau, the start of spring growth in meadows and steppe advanced until the mid-1990s, after which it retreated, so there was no overall significant trend over the period 1982-2006, despite continued warming and increases in spring NDVI (Yu *et al.*, 2012). These trends may be related to unfulfilled winter chilling requirements of the grasses. Herbarium records from Tibet show earlier flowering by 5 days per decade for a set of 41 species over the period 1961-2000 (Li *et al.*, 2013).

Recent changes in the growth rates of plants have also been widely reported and, where long records are available from tree rings, these changes can be linked to recent climate change (high confidence in detection, medium confidence in attribution to climate change). A reconstruction of summer temperatures for East Asia north of 23ºN for the period 800-1989, based on a network of tree-ring data, suggests that recent instrumental temperatures have exceeded those during past warm periods of similar length, but this difference was not statistically significant (Cook *et al*., 2013). In areas where temperature limits tree growth, recent decades have generally seen an increase in growth rates correlated with rising temperatures (e.g., Duan *et al*., 2010; Sano *et al*., 2010; Shishov and Vaganov, 2010; Borgaonkar *et al*., 2011; Xu *et al*., 2011; Li *et al*., 2012; Cao *et al*., 2012; Chen *et al*., 2012 a, b, c, d; Chen *et al*., 2013), while in areas where drought limits growth, there have been increases (Yang *et al*., 2010) or decreases (Dulamsuren *et al*., 2010a, 2011; Kang *et al*., 2012; Wu *et al*., 2012; Lu *et al*., 2013) in growth reflecting decreasing or increasing aridity. In the boreal forest zone, changes in tree growth varied between species and locations, despite consistent warming, with suggested reasons for decreased growth including drought stress, pollution, declining solar radiation, and direct temperature stress (Lloyd and Bunn, 2007; Goetz *et al*., 2011).

Where ground-based data is absent, satellite NDVI data can be used as a proxy for changes in vegetation density and photosynthetic capacity, which in turn reflect plant growth, although there are problems with both the NDVI data and its interpretation (Zhao *et al*., 2012; Xu *et al*., 2012). For Asia as a whole, the spatial pattern of trends in NDVI for 1988-2010 largely matches data on microwave-based surface soil moisture, with a greening trend dominant except where water is limiting (Dorigo *et al*., 2012). Changes in NDVI at high latitudes (>60ºN) in 1982-2008 show considerable spatial and temporal variability, despite a consistent warming trend, reflecting variations in water availability as well as non-climatic factors (Jeong *et al*., 2013). Arctic tundra generally showed increased greening between 1982 and 2005, while boreal forests were more variable, in agreement with tree-ring data (Goetz *et al*., 2011; de Jong *et al*., 2012). An overall greening trend for 2000-2011 north of the boreal forest correlated with increasing summer warmth and, to a lesser extent, summer ice retreat (Dutrieux *et al*., 2012). In China, NDVI trends have varied in space and between time periods, reflecting the varying balance between the positive impacts of rising temperature and negative impacts of increasing drought stress (Peng *et al*., 2011; Sun *et al*., 2012). In Central Asia, where NDVI is most sensitive to changes in precipitation (Gessner *et al*., 2013), there was a complex and heterogeneous pattern for 1982-2009, with an initial regional greening trend stalled or reversed in some areas and time periods (Mohammat *et al*., 2013). In the desert boundary regions (precipitation 200 mm yr^{-1}) of South, Central and Northern Asia, NDVI data showed that the bare soil area declined in 1982-1998, but expanded in 1998-2008 (Jeong *et al*., 2011). In the northern deserts (Karakum, Taklimakan and Gobi), these changes were related to an initial increase then decline in precipitation, while temperature continued to rise, while in the southern deserts (Lut and Thar) non-climatic factors appear to be more important. The steppe region of northern Kazakhstan has also shown an overall browning (lower NDVI) trend in 1982-2008, linked to declining precipitation (De Jong *et al*., 2012).

The carbon budget of all terrestrial ecosystems in East Asia (China, Mongolia, North and South Korea, Japan) from 1990 to 2009 was estimated using a combination of inventory and satellite-based data, ecosystem modeling (using 10 models), and atmospheric inversion models (Piao *et al*., 2012). Although there are large uncertainties in each approach, the results together suggest that the region as a whole was a significant carbon sink over this period (average -0.294 Pg C yr^{-1}), with the negative impacts of drought in some areas largely overcome by the positive impact of CO_2 fertilization.

The distributions of species and biomes. Also widely reported are changes in the distributions of plant and animal species: generally upwards in elevation (e.g. Soja *et al*., 2007; Round and Gale, 2008; Bickford *et al*., 2010; Kharuk *et al*., 2010 a, b, e; Moiseev *et al*., 2010; Chen *et al*., 2011; Jump *et al*., 2012) or polewards (e.g. Tougou *et al*., 2009; Ogawa-Onishi and Berry, 2013) in response to recent warming (high confidence in detection, medium confidence in attribution to climate change). Movements of dominant plant species can eventually lead to changes in the distributions of major vegetation types (biomes). Evidence for biome shifts has so far been reported only from the north of the region and at high altitudes, where it involves trees invading treeless tundra, steppe or alpine meadows, or the invasion of the forest understory by species from adjacent biomes (Soja *et al*., 2007; Kharuk *et al*., 2006; Bai *et al*., 2011; Singh *et al*., 2012; Wang and Liu, 2012; Ogawa-Onishi and Berry, 2013). In Uttarakhand, in the Indian Himalayas, the treeline has moved upwards into the alpine zone by an average of 388 m between the 1970s and 2006 (Singh *et al*., 2012).

Larch-dominated forest occupies about half the area of Siberia. Invasion of dark needle conifers (DNC, e.g. Siberian pine, spruce and fir) and birch into the larch habitat over the last three decades has been observed, correlating with winter temperature increases (Kharuk *et al*., 2010c). Siberian pine and spruce have high invasion potential both along the margin and in the centre of the larch-dominated zone. The process is wildfire dependant. On the western and southern margins of this zone, DNC regeneration has formed a second layer in the forest canopy, which could eventually replace the larch in the overstorey. In mixed stands, both larch and fir growth have increased over time, but the fir growth increase has been larger which may presage a shift in competitive balance between these species. Overall, it is *likely* that prevalence of evergreen conifers in areas currently dominated by deciduous larch species is increasing (Kharuk *et al*., 2010c, d; Osawa *et al*., 2010; Lloyd *et al*., 2011). At the same time, climate change has driven larch stand crown closure, and larch invasion into tundra at a rate of 3–10 m/year was observed in the northern forest-tundra ecotone in Siberia in the last three decades of the 20th century (Kharuk *et al*., 2006). Shrub expansion in arctic tundra as result of an increase in shrub growth, infilling of existing patches and the shrub line advancing into tundra has also been observed in the forest-tundra ecotone of Northern Asia (Myers-Smith *et al*., 2011; Blok *et al*., 2011; WG2 AR5 28.2.3.1.). Shrub growth is often strongly correlated with growing season temperatures, but is also influenced by fire, permafrost thaw and herbivory. Shrub and tree invasion of alpine meadows has also been reported in NW Yunnan, on the southeast edge of the Qinghai-Tibetan Plateau, between 1990 and 2009, and partly attributed to increasing temperatures and decreasing snow cover (Baker and Mosely, 2007; Brandt *et al*., 2013).

In northern Asia, the position of the ecotone between boreal forest and tundra is controlled largely by air temperature during the growing season and annual precipitation, but forest fires can also catalyze change (Soja *et al*., 2007). In contrast, soil moisture and light are the main factors governing the forest-steppe ecotone, although competition between trees and grasses, as well as fires, are also important (Soja *et al*., 2007; Zeng *et al*., 2008; Dulamsuren *et al*., 2010 a, b; Eichler *et al*., 2011). This ecotone in the western Khentey Mountains, northern Mongolia, has experienced a significant increase in summer temperature and decrease in summer precipitation since 1961. Siberian larch tree-ring analysis shows a strongly decreasing annual increment since the 1940s (Dulamsuren *et al*., 2010a). Regeneration of larch decreased as well and is now virtually lacking in this forest. Studies on a wider scale show a great deal of heterogeneity in the responses of Mongolian taiga forests to recent climate changes, but declines in larch growth and regeneration are more widespread than the opposite trend (Dulamsuren *et al*., 2010b).

Permafrost and glaciers. Degradation of permafrost, including reductions in area and increased thickness of the active layer, has been reported from parts of Siberia, Central Asia, and the Tibetan Plateau (Romanovsky *et al*., 2010; Wu and Zhang, 2010; Zhao *et al*., 2010; Yang *et al*., 2013) (*high confidence*). Russia contains more permafrost than any other country: more than half of the Russian part of Northern Asia lies in permafrost zones, which constitutes a significant portion of the Northern Hemisphere permafrost area (FNCRF, 2010). Monitoring in most of the permafrost observatories in Asian Russia shows substantial warming of permafrost during the last 20 to 30 years (Romanovsky *et al*., 2008, with supplement; 2010). Typical magnitude of warming varied from 0.5 to 2°C for different locations at the depth of zero annual amplitude. The main warming occurred between the 1970s and 1990s, with no significant warming after 2000. However, since 2007-2008 warming has resumed at many locations predominantly near the Arctic coasts. In Northwest Siberia, new closed taliks (areas of unfrozen ground) and an increase in the depth of preexisting taliks have been observed during last 20 to 30 years. Permafrost formed during the Little Ice Age is thawing at many locations and Late Holocene permafrost has begun to thaw at some undisturbed locations in northwest Siberia. Permafrost thawing is most noticeable within the discontinuous permafrost domain in Northern Asia, while in the continuous permafrost zone it is starting to thaw at some limited locations. As a consequence, the boundary between continuous and discontinuous permafrost zones is moving northward (Romanovsky *et al*., 2008, with supplement; 2010). Over many thousands of years, the soil layer and bogs in the permafrost zone of Northern Asia have been accumulating huge amounts of organic matter. As permafrost thaws, reinforcement of the greenhouse effect is possible due to growing emissions of greenhouse gases [WG2 AR5 FOD 4.3.4.4.; WG2 AR5 FOD 19.3.5.].

The Qinghai-Tibet Plateau (QTP) and Central Asian region, including parts of Southern Siberia, Mongolia, Western China, Kazakhstan, and adjacent countries/regions, represent the largest area underlain by mountain permafrost in the world. Ongoing monitoring at numerous sites across the QTP regions over the past several decades has revealed significant permafrost degradation caused by climate warming and human activities such as deforestation, forest fire, road construction and grazing: areas of permafrost are shrinking, the depth of the active layer is increasing, the lower limit of permafrost is rising, and the seasonal frost depth is thinning (Zhao *et al.*, 2010; Li *et al.*, 2008). The lower altitudinal limit of permafrost has moved up by 25 m in the north during the last 30 years and between 50 and 80 m in the south over the last 20 years in accord with long-term temperature measurements. Ground temperature at a depth of 6 m in 2001 has been higher by about 0.1-0.3°C than in 1996 according to data taken from seven natural sites on the Plateau (Cheng and Wu, 2007; Li *et al.*, 2008). Over the period from 1995 to 2007, the mean rate of increase of the active layer thickness (ALT) was 7.5 cm/year (Wu and Zhang, 2010). Ground temperatures at the bottom of the active layer warmed on average by 0.06°C/year over the past decade (Zhao *et al.*, 2010). In the alpine headwater regions of the Yangtze and Yellow Rivers, rising temperatures and permafrost degradation have resulted in lower lake levels, drying swamps and shrinking grasslands (Cheng and Wu, 2007; Wang *et al.*, 2011c).

In the Kazakh part of Tien Shan Mountains, the increase in permafrost temperature during 1974-2009 at depths of 14-25 m varied from 0.3°C to 0.6°C. The average active layer thickness (ALT) increased by 23% in comparison to the early 1970s. In the eastern Tien Shan Mountains, in the headwaters of the Urumqi River, China, significant permafrost warming took place as the air temperature increased (Marchenko *et al.*, 2007; Zhao *et al.*, 2010). In Mongolia, mean annual ground temperature at 10-15 m depth over the past 10-40 years increased on average by 0.02-0.03°C/year in the Hovsgol Mountain region, and by 0.01-0.02°C/year in the Hangai and Hentei Mountain regions. During the past 15–20 years permafrost warming was greater than during the previous 15-20 years (1970s-1980s). The average rate of increase in mean annual ground temperature in Mongolia was about 0.15°C/decade (Sharkhuu *et al.*, 2008; Zhao *et al.*, 2010).

Mountain glaciers occur across Asia from the Arctic to the tropics [WG1 AR5 SOD Ch. 4]. Those in the polar section of the Ural Mountains are small (< 1km^2) and in total lost 20-30% of their mass in 1953-1981, with the main change in 1953-1963 and intensive degradation resuming since 1990 (Anisimov *et al.*, 2008). Those in the Kodar Mountains of Southeast Siberia are also small (< 2 km^2) and the exposed ice area declined by c. 44% between ca. 1963 and 2010, with 40% loss since 1995, coinciding with a strong warming trend in June-August temperatures initiated in the 1980s (Stokes *et al.*, 2013). In Northeast Siberia, the Suntar Khayata Range glaciers lost 19.3% of their area between the middle of the 20th century and 2003 and the Chersky Range glaciers lost 28 % in 1970-2003 (Ananicheva *et al.*, 2005, 2006). Changes in the Kamchatka glaciers are driven by both temperature increase and volcano activity, with the area of some glaciers decreasing, while others increased because they are covered by ash and clinker (Anisimov *et al.*, 2008). Glaciers of Georgia and Azerbaijan on the southern macroslope of the Greater Caucasus Range decreased in area by 31.2% in 1895-2000 (Anisimov *et al.*, 2008). Yao *et al.* (2012) estimated that reduction in total area for glaciers on Tibetan Plateau and the surrounding areas during the past three decades, from the 1970s to 2000s, was c. 9%. In Papua, western Indonesia, the tropical mountain glaciers on Puncak Jaya have retreated rapidly since 1972, with rising temperatures thought to be the major factor (Prentice and Glidden, 2010; WG1, Ch. 4, AR5 SOD). Central Asian and Altai-Sayan glaciers are considered in more detail in the case study [24.9.3] and the Himalayan glaciers are considered in section 24.4.1 and in WG1 AR5 SOD Ch. 4.

24.4.2.3. Projected Impacts

The projected impacts in the literature assessed here include extrapolations from the observed trends, inferences from experiments, and projections from a variety of modeling approaches, based on projected climate change and projections for other factors, including carbon dioxide levels and land-use changes.

Phenology and growth rates. If air temperatures continue to rise, current trends towards an earlier spring and longer growing season in temperate and boreal forest areas are expected to continue, although photoperiod or chilling requirements may reduce the response in some plant species (Richardson *et al.*, 2013). Changes in the timing and amount of precipitation will be at least as important as warming for semi-arid and arid ecosystems, making growth and phenological responses harder to predict, as shown by the varied responses of different plant species to experimental warming in the northern Mongolian steppe (Liancourt *et al.*, 2012). The phenological drivers for tropical forests are not yet understood.

Distributions of species and biomes. The current distribution of vegetation across the region is controlled primarily by climate (particularly temperature, rainfall and snowfall, and their seasonality), modified over large areas by soils, permafrost, topography, and a variety of human impacts. In the longer term, therefore, climate change is expected to change this distribution (e.g. Wang, 2013). However, the rate at which this change in vegetation is realized will be constrained by many factors, including seed dispersal, competition from established plants, rates of soil development, and habitat fragmentation. Atmospheric CO_2 concentrations are an additional factor, with rising concentrations increasingly favoring C3 over C4 plants, and thus an increase in woody vegetation at the expense of grassland (Higgins and Scheiter, 2012; Wang, 2013).

Climate projections for Asia strongly suggest that the warming trend will continue, but projections for precipitation are still uncertain [WG1 AR5 SOD Ch. 14]. In Northern Asia, these changes in climate will lead to large and relatively predictable changes in the distribution of potential natural ecosystems (Ni, 2011; Tchebakova *et al.*, 2011; Insarov *et al.*, 2012), although the transitional stages will be less predictable. If current climate projections are correct, it is *likely* that the boreal forest will expand northward and eastward, and the tundra area will decrease, during the 21st century (Golubyatnikov and Denisenko, 2007; Korzukhin and Tcelniker, 2010; Lucht *et al.*, 2006; Sitch *et al.*, 2008; Tchebakova *et al.*, 2010; Woodward and Lomas, 2004). However, for a shorter time horizon, some forest retreat and tundra advance by 2020 in Central Siberia have been projected (Tchebakova *et al.*, 2011). Because models vary in accordance with their structure as well as biome classifications, climatic projections, CO_2 level and other characteristics used as inputs, the magnitude of the forest expansion varies greatly across models: Tchebakova *et al.* (2010) and Lucht *et al.* (2006) project that 93-100% of tundra area will be covered by boreal forest at the end of 21st century, Kaplan and New (2006) predict a 42% reduction in tundra area between 2026 and 2060, whereas Golubyatnikov and Denisenko (2007) estimate that 97% of tundra will remain unaltered by the mid-21st century.

The combination of boreal forest expansion and the continued invasion of the existing larch-dominated forest by dark-needle conifers could lead to a situation where larch reaches the Arctic shore, as has happened previously in the Holocene, whereas the traditional area of larch dominance will turn into mixed taiga forest (Kharuk, 2006, 2010c). Both replacement of summer-green conifers (larch) with evergreen conifers (DNC) and expansion of boreal forest and shrubs into regions now occupied by tundra decrease albedo. This change would cause heating of the atmosphere, a response that, in its turn could possibly accelerate the replacement of larch by DNC and of tundra by boreal forest (McGuire *et al.*, 2007; Kharuk *et al.*, 2006, 2010d). Energy budget feedback to the regional summer climate from the tundra to forest transition is estimated at 5.0 Wm^{-2} (McGuire *et al.*, 2007). Overall there is a risk that future climate and environmental change, along with fire and permafrost degradation, could change some Siberian ecosystems, particularly disturbed forests and ecosystems on permafrost, from carbon sinks to sources of both CO_2 and CH_4 (Shvidenko *et al.*, 2013).

The direction and rate of change in the extent of steppe vegetation is less clear, in part because of uncertainty in precipitation trends. One projection is that steppe area will increase by 27% for the decade beginning in 2090 (Tchebakova *et al.*, 2010) while another is that it will decrease by up to 65% for late 2030s–early 2050s (Golubyatnikov and Denisenko, 2007). Reasons for the differences between these estimates include different projection horizons and vegetation classifications used. Increasing aridity may expand the deserts of northern China, and push the steppe to the northeast (Zhang *et al.*, 2011), while a retreat of the southern limit of the taiga would expand the steppe area in the north (Dulamsuren *et al.*, 2010b).

The forest regions of East Asia are expected to remain forested, but climates suitable for evergreen forests will expand north into the deciduous forest zone and the potential distribution of tropical forests will expand along China's southern coast (Choi *et al.*, 2011; Wang, 2013). As observed elsewhere in the world, however, vegetation changes within lowland forest regions are expected to lag behind climate change by decades or even centuries, as fragmentation limits seed dispersal and long-lived forest dominants persist (e.g., Bertrand *et al.*, 2011; Zhu *et al.*, 2012). For example, climate models predict a large increase in the potential habitat for the evergreen broad-leaved tree species *Quercus acuta* in Japan, but short-distance seed dispersal by rodents will limit the ability of this species to occupy new areas (Nakao *et al.*, 2011). On the Tibetan Plateau, multiple vegetation and climate models suggest that alpine vegetation will be largely replaced by forest and shrubland, with tundra and steppe retreating to the north of the plateau (Liang *et al.*, 2012; Wang, 2013). In drier parts of the plateau, permafrost degradation will favor plants that are tolerant of water stress (Cheng and Wu, 2007; Yang *et al*., 2013). The same models suggest that a large area of desert will persist in northwest China (Wang, 2013). Impacts in Central and West Asia will depend critically on the changes in precipitation, which are still highly uncertain. Projections for China from an atmospheric-vegetation interaction model under the SRES B2 scenario suggest that the arid northwest of the country is the most vulnerable ecoregion, with severe damage to desert ecosystems possible (Wu *et al*., 2010).

In the tropics and subtropics (<30ºN), many areas, including much of the Arabian Peninsula, India, southeastern China, and Southeast Asia, are expected to have climates by 2080 that do not occur anywhere on Earth at present (García- López and Allué, 2012), making predictions particularly difficult. In India, a dynamic vegetation model (IBIS) was combined with climate projections for 2100 (HadRM3 model, A2 and B2 scenarios) to produce projections for forest areas (Chaturvedi *et al*., 2011). More than a third of forest grids were projected to change forest type, with most changes from deciduous to evergreen forest in response to increasing rainfall, although fragmentation, loss of seed dispersal agents, and other human pressures are expected to slow these changes. The forests of the upper Himalayas, parts of Central India, northern Western Ghats and Eastern Ghats, appear to be most vulnerable to climate change. In the equatorial tropics, the relatively small annual temperature range means that by 2100 many lowland habitats are likely to experience temperatures every day that are outside the current range of extremes (Beaumont *et al*., 2010). The potential impacts of these novel climatic conditions are largely unknown (Corlett, 2011). If the frequency and severity of droughts increases, this is *likely* to interact with forest fragmentation and logging to increase fire risk (Daniau *et al*., 2012) and could also increase the risk of drought-induced tree mortality (Kumagai and Porporato, 2012).

An increasing number of studies have projected impacts on animals using a variety of modeling techniques. Hughes *et al*. (2012) projected the effects of both climatic (A2 and B1 scenarios) and vegetation changes on the distribution and diversity of bats in SE Asia. All projections predicted widespread declines in local bat species richness, northward range shifts for many species, and large reductions in the distribution of most species. Projections for the potential ranges of 63 species of galliform birds (pheasants, partridges and their relatives) in China (A2 scenario, 2071-2100) showed large (>50%), mostly northward, range shifts for 29 species (Li *et al*., 2010), while projections for the 13 species of nuthatches (Sittidae) in Asia (A2 and B2 scenarios, 2040-2069) found that most ranges would retract along their southern fringes and at lower elevations, with the largest range contractions in SE Asia and peninsular India (Menon *et al*., 2009). Projections for 17 endemic bird species in Taiwan (A2 and B2 scenarios, 5 GCMs) suggested 15 species would decrease their area of distribution by 2100 because of a shift to higher elevations, while two species from relatively low altitudes would increase (Ko *et al*., 2012). Projections for the distributions of 161 butterfly species in Thailand (A2 and B2 scenarios, 2070-2099) suggested that species richness within currently protected areas will decline c. 30%, but that these areas will continue to include a similar proportion of the highest priority sites for conservation (Klorvuttimontara *et al*., 2011). Projections for three dominant bamboo species in the Qinling Mountains, China (A2 and B2 scenarios, four GCMs) suggest substantial reductions in their ranges by 2100, with potentially adverse consequences for the giant pandas for which they comprise almost the entire current diet (Tuanmu *et al*., 2012). Projections for vegetation cover in the range of the threatened Yunnan snub-nosed monkey in southwest China in 2050 and 2100 (A1B scenario) suggest an increased area of the most suitable habitat, but greater fragmentation (Wong *et al*., 2013). Projections for snow leopard habitat in the Himalayas (15 GCMs, downscaled, B1, A1B and A2 scenarios) suggest this may contract by around 30% as forests move upslope and replace the open habitats this species needs (Forrest *et al*., 2012).

Permafrost. In the Northern Hemisphere as a whole, a 20-90% decrease in permafrost area and a 50-300 cm increase in active layer thickness (ALT) driven by surface warming is projected for 2100 by different models under SRES A1B, A2, B1 scenarios (Schaefer *et al*., 2011). The wide range of permafrost degradation projections may be result of different scenarios used, intensity of land atmosphere feedbacks and of difference in model internal structures. In Asia, it is *likely* that permafrost degradation during the 21st century will spread from the southern and low-altitude margins, advancing northwards and upwards as numerous models predict, but rates of change vary greatly between different model projections (Cheng and Wu, 2007; Riseborough *et al*., 2008; Romanovsky *et al*., 2008, with supplement; Anisimov, 2009; Eliseev *et al*., 2009; Nadyozhina *et al*., 2010; Schaefer *et al*., 2011; Wei *et al*., 2011). The spatially distributed permafrost model (Sazonova and Romanovsky, 2003) has been applied to the entire permafrost domain of Northern Eurasia, Central Asia and the QTP (Romanovsky *et al*., 2008, with supplement). If air temperatures continues to increase in accordance with the MIT 2D climate model output for the

21st century (Sokolov and Stone 1998), that is 2.2°C warming by 2031-50 and 4.7°C by 2080-2099 compared with 1981-2000 (Romanovsky *et al*., 2008, with supplement), models show that permafrost that is presently discontinuous with temperatures between 0 and -2.5° C will cross the threshold by the end of 21st century and will be thawing actively. The most intense permafrost degradation in Russia is projected for Northwest Siberia. According to this model, the Late Holocene permafrost will be actively thawing everywhere except for the south of East Siberia and the Far East of Russia by the middle of 21st century. Almost all Late Holocene permafrost will be thawing, and some Late Pleistocene permafrost will begin to thaw in Siberia by the end of 21st century (Romanovsky *et al*., 2008, with supplement). Near-surface permafrost is expected to remain only in Central and Eastern Siberia and in part of Tibet in the late 21st century. Depths of seasonal thaw are projected to exceed 1 m (2 m) in the late 21th century under the SRES B1 (A1B or A2) scenario in these regions (Eliseev *et al*., 2009).

On the Qinghai-Tibet Plateau (QTP) and in northeastern China, substantial retreat of permafrost is expected during the 21st century due to the combined influence of climatic warming and increasing anthropogenic activities. No significant change will take place in permafrost conditions on the QTP over the next 20 to 50 years, but more than half of the permafrost in the southern and eastern parts of the plateau may become relict and/or even disappear by 2100 according to modeling results (Cheng and Wu, 2007). The result of permafrost degradation can dry the ground surface, and desertification may become an important environmental issue for the QTP (Cheng and Wu, 2007). In northeastern China, the southern limit of permafrost is expected to shift northwards, the total permafrost area to shrink, and the area of unstable permafrost to expand, with adverse consequences for associated wetlands and forests (Sun *et al*., 2011; Wei *et al*., 2011).

Inland Waters. Climate change impacts on inland waters will continue to interact over most of Asia with a wide range of other human impacts, including dam construction, pollution, and catchment land-use changes (see also Chapter 3, this volume). Increases in water temperature will be the most pervasive impact of climate change on both living organisms and a wide range of temperature-dependent ecological, chemical, and physical processes (Hamilton, 2010; Dudgeon, 2011, 2012). Coldwater fish will be threatened as rising water temperatures make much of their current habitat unsuitable (Yu *et al*., 2013). The other major impact of climate change is expected to be on flow regimes in running waters and consequently on riverine habitats and species that are sensitive to flow extremes (droughts and floods) [see Box CC-RF: Freshwater ecosystems and altered river flows]. However, in the Mekong River, planned hydropower reservoirs are expected to have a larger impact on flow regimes than climate change (Lauri *et al*., 2012). Regionally threatened natural habitats that depend on seasonal inundation, including floodplain grasslands and freshwater swamp forests, will be particularly vulnerable (Maxwell, 2009; Bezuijen, 2011). In Cambodia, the unique and hugely productive Tonle Sap Lake floodplain depends on an annual flood pulse from the Mekong River (Lamberts and Koponen, 2008; Arias *et al*., 2012). Changes in river flow, in turn, have a direct impact on the freshwater to saltwater gradient where the river meets the sea, with reduced dry season flows combining with sea-level rise to increase saltwater intrusion in deltas (Hamilton, 2010; Dudgeon, 2012), although non-climatic human impacts will probably continue to dominate in most Asian estuaries (Syvitski *et al*., 2009). Lakes will also be affected by climate change, but in most of Asia it is very difficult to disentangle the impacts of water pollution, hydro-engineering and climate change (Battarbee *et al*., 2012). The ecology of China's largest freshwater body, Lake Poyang, is sensitive to the hydrological regime, which is potentially influenced by both engineering projects and climate change (Ye *et al*., 2011; Zhang *et al*., 2012). The unique ecosystem of Lake Baikal is expected to be impacted most by changes in ice duration and transparency, followed by water temperature and wind mixing (Moore *et al*., 2009). Recent long-term trends towards earlier ice break-up, later freeze-up, and decreasing duration and thickness of ice cover, in close correspondence with rising air temperatures, are expected to continue in Arctic lakes and rivers, with unknown implications for freshwater and riparian ecosystems (Prowse *et al*., 2011).

Thresholds and irreversible changes. Specific thresholds for terrestrial and inland water systems have not yet been identified. Studies of future climate change impacts on terrestrial ecosystems in China under the SRES B2 scenario suggest that moderate to severe impacts will increase significantly when temperatures increase by more than 2ºC, but do not suggest a sharp threshold (Wu *et al*., 2010). Species extinctions are the most likely irreversible change, with species that are unable to track climate change as a resulted of limited dispersal ability, habitat fragmentation, or non-climatic constraints, such as specialized soil requirements, most vulnerable (Heller and Zavaleta, 2009).

24.4.2.4. Vulnerabilities to Key Drivers

Changes in temperature are the most robust predictions and the most pervasive climate impact. Adverse impacts from rising temperature are *likely* in the wetter areas of north Asia and at high altitudes, with permafrost melting impacting ecosystems across large areas (Cheng and Wu, 2007; Tchebakova *et al.*, 2011), but the impacts of higher temperatures in the tropical and subtropical lowlands are still unclear (Corlett, 2011). The biodiversity of isolated tropical, subtropical, and warm-temperate mountains may be most vulnerable to warming, because many species already have small geographical ranges that will shrink further in a warming climate (Liu *et al.*, 2010; Chou *et al.*, 2011; La Sorte and Jetz, 2011; Noroozi *et al.*, 2011; Peh *et al.*, 2011; Jump *et al.*, 2012; Tanaka *et al.*, 2012a). Many freshwater habitats are similarly isolated and their restricted-range species may be equally vulnerable (Dudgeon, 2012). Freshwater systems are also potentially vulnerable to increases in the frequency and intensity of extreme rainfall events (droughts or floods), even if average conditions are unchanged (Hamilton, 2010).

For much of Asia, increases in aridity, as a result of declining rainfall and/or rising temperatures, are the key concern. Because aridity is projected to increase in the northern Mongolian forest belt during the 21st century (Sato *et al.*, 2007), the larch covered area will *likely* be reduced (Dulamsuren *et al.*, 2010a). This will have far-reaching consequences for Mongolia's biodiversity and capacity to store water and carbon. It is likely it will also have significant socioeconomic consequences because the economy depends on the sustainable exploitation of natural resources. Even where mean rainfall remains adequate, any increase in drought frequency and/or severity will increase vulnerability to human-caused fires. The frequency and scale of both natural and manmade fires have recently increased in the tundra and taiga-tundra zones, as a result of warming, especially summer droughts (Kumpula *et al.*, 2011; Nuttall 2005; Walker *et al.*, 2011). If droughts intensify in the tropical lowlands of SE Asia, then the synergies between warmth, drought, logging, forest fragmentation and fire (Daniau *et al.*, 2012), which may be further acerbated by feedbacks between deforestation, smoke aerosols and reduced regional rainfall (Aragão, 2012; Tosca *et al.*, 2012), could greatly increase the vulnerability of fragmented forest landscapes to both fire and climate change.

24.4.2.5. Adaptation Options

The capacity of natural ecosystems to adapt of their own accord is currently poorly understood (WGII AR5 FOD Ch. 4), but some of the 'impacts' reported in this chapter, such as phenological changes, could be considered adaptive if they help the species to survive and flourish. Suggested general strategies for maximizing the adaptive capacity of ecosystems include: reducing non-climate impacts, monitoring climate impacts, maximizing landscape connectivity, and making protected area networks robust to future climate scenarios (Hannah, 2010; Shoo *et al.*, 2011; Klorvuttimontara *et al.*, 2011; Murthy *et al.*, 2011; Mandych *et al.*, 2012). In northeastern China, where climate change is expected to increase the risk of damaging forest fires, strengthening early warning and monitoring systems, paying attention to post-fire recovery, and the use of prescribed burning to reduce fuel loads are among the suggested strategies for adaptation (Tian *et al.*, 2011). For Papua New Guinea, three general strategies have been suggested for adapting biodiversity conservation to climate change: conserving habitats across the full range of physical settings, including combinations of elevation and geology; protecting 'climatic refugia', where climate change is expected to be less than the regional mean; and increasing landscape connectivity (Game *et al.*, 2011). A trial application of a formal process for adaptation to protect biodiversity in Vietnam used the 13 terrestrial ecoregions as basic planning units, for each of which social, economic and ecological trends were assessed, climate change scenarios identified, and key policy responses and actions developed (Booth *et al.*, 2013). More generally, there is increasing recognition of the need to incorporate climate change adaptation into all forest conservation and development programs (e.g. in India; Chaturvedi *et al.*, 2011; Murthy *et al.*, 2011). There is a lack of scientifically well-founded recommendations and programs aimed at development of adaptation plans for the forest-tundra ecotone in North Asia at the state level (Anisimov *et al.*, 2010). Comprehensive monitoring, assessments and projections that can anticipate numerous development scenarios are needed to elaborate a plan for adaptation to the cumulative effects of resource development, climate change, and demographic changes that are occurring (Walker *et al.*, 2011). Similar problems are widespread in other parts of Asia, although awareness of the need for adaptation plans is increasing.

At the species level, distribution models are increasingly used to forecast the potential future distributions of species in the face of climate change, identifying areas where the species is most likely to persist and where it is most threatened, as well as potential new habitats (e.g., Higa *et al*., 2013; Yu *et al*., 2013). Restoration of ecological habitats within and between protected areas may help facilitate the movement of species across climatic gradients in response to climate change (Klorvuttimontara *et al*., 2011; Hughes *et al*., 2012). Key seed dispersal agents may need to be protected because of their potential role in long-distance plant movements in fragmented landscapes (Corlett, 2009). Assisted migration (or 'managed translocation') of genotypes and species is an increasingly common suggestion for plants and animals where adjustments to climate change are constrained by natural rates of movement, although the risks and benefits in each case need to be considered carefully (e.g. Liu *et al*., 2010; Olden *et al*., 2010; Tchebakova *et al*., 2011; Ogawa-Onishi *et al*., 2011; Dudgeon, 2012; Ishizuka and Goto, 2012). *Ex situ* conservation can provide back-up for some of the populations and species that are most at risk from climate change (Chen *et al*., 2009).

24.4.3. Coastal Systems and Low-Lying Areas

24.4.3.1. Sub-Regional Diversity

Asia's long coastline includes the full global range of muddy, sandy, and rocky shore types, as well as extensive estuarine systems. Asia's tropical and subtropical coasts support an estimated 45% of the world's total mangrove forest and include the most mangrove-rich country (Indonesia) and the largest single tract of mangrove forest (the Sundarbans of Bangladesh and India) (Giri *et al*., 2011). Low-lying areas near the coast of equatorial SE Asia support most of world's peat swamp forests (see also 24.8.2), which are a massive store of carbon, as well as extensive areas of other forested swamp types. Intertidal salt marshes are widespread along temperate and arctic coasts, while a variety of non-forested wetlands occur inland, including freshwater marshes and peat bogs. Asia also supports around 40% of the world's coral reef area (Spalding *et al*., 2001; Burke *et al*., 2011), mostly in SE Asia, with the most extensive reefs and the world's most diverse reef communities in the 'coral triangle' (in Indonesia, Malaysia, the Philippines, and Papua New Guinea; see also Chapter 30, this volume, Box 30-3). Seagrass beds are also widespread, although less well studied, and Asia supports the majority of the world's seagrass species (Green and Short, 2003). Six of the seven living species of sea turtle are found in the region and five species nest on Asian beaches (Spotila, 2004). Kelp forests and other seaweed beds are important on temperate coasts (Bolton, 2010; Nagai *et al*., 2011). Permafrost and sea-ice influence coastal processes in the far north (Are *et al*., 2008). The sea-ice itself supports a specialized community of mammals, including the polar bear, walrus, several species of seals, and the beluga and bowhead whales, as well as birds, fish and other species (Kovacs *et al*., 2011; Chapter 28, Sections 28.2.3.3. and 28.2.3.4.).

24.4.3.2. Observed Impacts

Most of Asia's non-Arctic coastal ecosystems are under such severe pressure from non-climate human impacts that climate impacts are hard to detect. For example, observations of impacts from rising sea levels in Asia have reflected coastal subsidence rather than the impact of climate change, since most major deltas in Asia are now sinking (as a result of groundwater withdrawal, floodplain engineering, and trapping of sediments by upstream dams) at rates many times faster than the global sea-level is rising (Syvitski *et al*., 2009). Widespread impacts can be attributed with *high confidence* to climate change, however, for coral reefs, where the temporal and spatial patterns of large-scale bleaching events generally correlate well with higher than normal sea surface temperatures (Hoegh-Guldberg, 2011; Krishnan *et al*., 2011; Coles and Riegl, 2013; Lough, 2012). Increases in coastal water temperatures are also one of the most plausible explanations for widespread declines in beds of large seaweeds in temperate Japan: the Isoyake phenomenon (Nagai *et al*., 2011). Warming coastal waters have also been implicated in the northwards expansion in Japanese waters of tropical and subtropical macroalgae and toxic phytoplankton (Nagai *et al*., 2011), fish (Tian *et al*., 2012), and tropical corals, including key reef-forming species (Yamano *et al*., 2011), over recent decades. The decline of large temperate seaweeds and expansion of tropical species in southwest Japan has been linked to rising sea surface temperatures (Tanaka *et al*., 2012b), and the changes in the seaweed community have, in turn, impacted fish communities (Terazono *et al*., 2012).

The impact of warming is also evident on sparsely populated Arctic coastlines, where erosion appears to be accelerating. In Arctic Asia, changes in permafrost and in storm wave energy caused by sea-level rise and sea-ice retreat have resulted in increased coastal retreat, in spite of the fact that most of the year coasts are protected by continuous ice cover (Are *et al*., 2008; Razumov, 2010; Handmer *et al*., 2012). In the central part of the Laptev Sea, coastal retreat has accelerated by 1.5-2 times in recent decades (Anisimov *et al*., 2010). Average erosion rates of Asian Arctic coastlines range from 0.27 m/year (Chukchi Sea) to 0.87 m/year (East Siberian Sea). A number of segments in the Laptev Sea and in the East Siberian Sea are characterized by rates greater than 3 m/year (Lantuit *et al*., 2012). The decline in the extent of arctic sea-ice documented in AR4 has continued, but the impacts on ice-dependent species and ecosystems in Arctic Asia are so far unclear [WG1 AR5 SOD Ch. 4; WG2 AR5 FOD Ch. 28].

24.4.3.3. Projected Impacts

It is *likely* that there will be an overall increase in marine biodiversity at temperate latitudes as temperature constraints on the distributions of warm-water taxa are relaxed, but biodiversity in tropical regions may fall if, as some evidence suggests, tropical marine species are already near their thermal maxima (Cheung *et al*., 2009, 2010). An experimental study in Singapore found that the activity and survival of marine invertebrates in seven phyla was reduced by water temperatures only 2-3ºC above present (Nguyen *et al*., 2011). In contrast, two shallow-water marine fish species from Indonesia showed exceptional tolerance of high temperatures (Eme *et al*., 2011). Individual fish species are projected to shift their ranges northwards in response to rising sea surface temperatures (Tseng *et al*., 2011; Okunishi *et al*., 2012; Tian *et al*., 2012). A combination of projected shifts in species distributions and expected changes in total primary production may lead to a regional redistribution of fisheries potential, with large declines in the tropics and large increases in high-latitude regions (Cheung *et al*., 2010; WG2 AR5 FOD Ch. 6). A more recent study using a very different modeling approach produced broadly similar projections (Blanchard *et al*., 2012). Another modeling study suggested that the combined effects of changes in distribution, abundance and physiology will reduce the body size of marine fishes, particularly in the tropics and intermediate latitudes (Cheung *et al.,* 2012). Projected impacts are greatest for coral reefs, where a continuation of current trends in sea-surface temperatures and ocean acidification suggests that existing coral-dominated reefs will largely disappear by mid-century (Vivekanandan *et al*., 2009; Hoegh-Guldberg, 2011; Burke *et al*., 2011). In the seas around Japan, warming would permit the expansion of coral habitats to the north, but ocean acidification is expected to limit this, with coral habitats sandwiched between excessive warming to the south and acidification in the north (Yara *et al*., 2012). However, the capacity of coral communities to adjust by changes in species composition, or by the acclimation and/or adaptation of coral species, is not well understood (Ateweberhan and McClanahan, 2010; Fabricius *et al*., 2011; Guest *et al*., 2012; Howells *et al*., 2012). The impacts of ocean acidification on other organisms are also currently poorly understood (Hendriks *et al*., 2010; WGII AR5 FOD Ch. 6).

The uncertainties in future sea-level rises are still large (WG1 AR5 SOD Ch. 13). The major projected impacts include coastal flooding, increased erosion, and saltwater intrusion into surface and groundwater. In the absence of other impacts, coral reefs may grow fast enough to keep up with rising sea-levels (Brown *et al*., 2011), but mangroves, salt marshes, and seagrass beds will decline unless they can move landwards or they receive sufficient sediment to keep pace, and beaches may erode (Gilman *et al*., 2008; Bezuijen, 2011; Forbes, 2011). Loucks *et al*. (2010) predict a 96% decline in tiger habitat in Bangladesh's Sunderbans mangroves with a 28 cm sea-level rise if sedimentation does not increase surface elevations. Coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea-levels. However, in most river deltas, the global sea-level rise will continue to be outpaced by local subsidence for non-climatic reasons (Syvitski *et al*., 2009).

Cyclones affect most of the Asian coastline, except in the far north, west, and 10° either side of the equator. Natural coastlines are resilient, but large cyclones can have a devastating impact on isolated ecosystem fragments. However, current trends in cyclone frequency and intensity are unclear (Seneviratne *et al*., 2012; WG1 AR5 SOD Ch. 14; see Box CC-TC). A combination of cyclone intensification and sea-level rise could potentially result in a large increase in coastal flooding (Knutson *et al*., 2010). Cyclones can also have a large impact on the productivity of coastal waters through increased nutrient run-off and water circulation (Qiu *et al*., 2010). In addition to any changes in cyclone activity, sea turtles nesting beaches may be impacted by rising temperatures and sea-levels, but the capacity of turtle populations to adapt is not well understood (WGII AR5 FOD Ch. 6).

In the Asian Arctic it is *likely* that rates of coastal erosion will increase as a result of interactions between rising sea-levels and projected changes in permafrost and the length of the ice-free season (Pavlidis *et al*., 2007; Lantuit *et al*., 2012). The most sensitive region to potential increases in permafrost and sea surface temperatures on the Asian Arctic coast is the Kara Sea region (Lantuit *et al*., 2012). Sea level rise may have different influences on coastal processes depending on the sediment budget equilibrium, playing a minor role if there is a strong imbalance in the sediment budget, but appearing to be the main factor if the sediment budget is balanced (Leont'yev, 2008). The most prominent changes in the dynamics and morphology of the coastal zone are expected where the coasts are composed of loose permafrost rocks and are therefore subject to intensive thermal abrasion. Assuming that sea level will rise by 0.5 m over the next century, modeling studies predict that the rate of recession due to thermal erosion will increase 1.5- to 2.6-fold for the coasts of Laptev Sea, East Siberian sea and of West Yamal in the Kara Sea compared to the rate observed in first years of the XXI century. This rate will vary across the Asian Arctic coast from 3 to 9 m/year (Pavlidis *et al*., 2007).

24.4.3.4. Vulnerabilities to Key Drivers

As discussed in the previous section, offshore marine systems appear to be most vulnerable to rising water temperatures, plus the impacts of ocean acidification, particularly for calcifying organisms such as corals. Sea-level rise will be the key issue for many coastal areas, particularly if it is combined with changes in cyclone frequency or intensity, or in Arctic Asia, with a lengthening open-water season. The expected continuing decline in the extent of sea-ice in the arctic may threaten the survival of some ice-associated mammals and other organisms (WG1 AR5 SOD Ch. 4; WGII AR5 FOD Ch. 6), with the expansion of human activities in previously inaccessible areas an additional problem (Kovacs *et al*., 2011).

24.4.3.5. Adaptation Options

The connectivity of marine habitats and the relatively high dispersal abilities of many marine organisms should maximize the capacity for autonomous (spontaneous) adaptation in natural and semi-natural coastal systems and is expected to keep the extinction rate below that projected for terrestrial habitats (Cheung *et al*., 2009). Where natural connectivity is insufficient, as between the heat-tolerant coral populations of the Arabian/Persian Gulf and the Southeast Asian reefs threatened by rising temperatures, than ‘assisted colonization’ (by moving adult fragments or larval stages) is a possible option, although only as a last resort (Coles and Riegl, 2013). Creating marine protected areas in locations where sea surface temperatures are projected to change least may increase their future resilience (Levy and Ban, 2013). ‘Hard’ coastal defenses, such as dykes, levees and sea walls, may protect settlements, but at the cost of preventing adjustments by mangroves, salt marshes and seagrass beds to rising sea-levels. The acquisition of landward buffer zones that provide an opportunity for future inland migration could mitigate this problem (Erwin, 2009), but is rarely practical. Large sections of Asia’s coastline are already highly degraded and there are many opportunities for restoration of coastal systems (Crooks *et al*., 2011).

24.4.4. Food Production Systems and Food Security

It is projected that climate change will affect food security in the middle of the 21st century, with the largest numbers of food-insecure people located in South Asia (Porter *et al*., 2014 Chapter 7).

24.4.4.1. Sub-Regional Diversity

AR4 Section 10.4.1.1 pointed out that there will be regional differences in the impacts of climate change on food production. Research since then has validated this divergence and new data are available especially for West and Central Asia (see Tables 24-5 and 24-6). These differences will be apparent in the discussion below. In addition, new studies have supplied more detailed data about the impacts on crop production. In AR4 Section 10.4.1, climate change was projected to lead mainly to reductions in yield. New research shows there will also be gains for specific regions and crops in given areas. Thus, the current assessment encompasses an enormous variability depending on the regions and the crops grown.

24.4.4.2. Observed Impacts

While there is consensus that climate change will affect food production systems and food security, the precise nature and timing of these impacts, as well as their implications for human livelihoods, are still uncertain (Hertel *et al.*, 2010). There are limited data in Asia for observed impacts of climate change on food production systems. In Jordan, it was reported that in 1999, the total production and average yield for wheat and barley were the lowest among the years 1996 to 2006. This could be explained by the low rainfall during that year, which was 30% of the average (high confidence in detection, low confidence in attribution). These results suggest that both crops are vulnerable to climatic variations (Al-Bakri *et al.*, 2010). In China, rice yield responses to recent climate change at experimental stations were assessed for the period 1981–2005 (Zhang *et al.* 2010). The study concluded that there are variable climate to yield relationships, considering inter-annual variations at a regional scale. In some places, yield fluctuations were positively correlated with temperature when they were also positively related with solar radiation. However, in other places, lower yield with higher temperature was accompanied by a positive correlation between yield and rainfall (high confidence in detection, high confidence in attribution). Crop responses to high temperatures can be accurately estimated from experiments in controlled environments; however, such experiments are generally not feasible given the large number of crops. Instead, the general effects of climate change on a wide variety of crops can be estimated by collecting and analyzing data from various agricultural systems on yield changes due to recent regional temperature increases. In Japan, where mean air temperature has risen at 1ºC per the past 100 years, information on changes in agricultural production (cereal, soybean, fruit tree, vegetable and livestock), were collected by surveys of the public institutes of agricultural research in 47 prefectures. Recent effects of warming were analyzed by comparing those data to literature on relations between crop growth and temperature (Sugiura, et al, 2012). Effects of recent warming, include phenological changes in many crops, increases in fruit coloring disorders and incidences of chalky rice kernels, reductions in yields of wheat, barley, vegetables, flowers, milk and eggs, and alterations in the type of disease and pest.

Another possible approach to assessing observed impacts of climate change is to combine local knowledge with scientific assessments. For example, the nomadic herders of Mongolia demonstrated a detailed understanding of weather and climate, including an account of climatic change that integrates multiple indicators (Marin, 2010). However, their evidence of change is only partly supported (or even contradicted) by meteorological records, larger scale predictions and general circulation models.

24.4.4.3. Projected Impacts

Production. AR4 Section 10.4.1.1 mainly dealt with cereal crops (rice, wheat corn). Since then, impacts of climate change have been modeled for additional cereal crops and sub-regions. In semi-arid and arid regions of Western Asia, a review paper (Ratnakumar *et al.*, 2011) has shown that rainfed agriculture is sensitive to climate change both positively and negatively. A rise in CO_2 concentration may benefit the semi-arid crops by increasing crop water-use efficiency and net photosynthesis leading to greater biomass, yield and harvest index. C_3 plants responded with a higher average increment in biomass production than C_4 plants. For example, wheat yield increased by 10-20% with elevated CO_2 (350 ppm to 700 ppm). In Yarmouk basin, Jordan, simulation with DSSAT showed that wheat and barley yields will decline by 10-20% and 4-8% respectively with a 10-20% reduction in rainfall (Al-Bakri *et al.*, 2010). Conversely, with an increase in rainfall of 10–20% the expected yield increased by 3–5% for barley and 9–

18% for wheat. However increased air temperatures had mixed results. Increasing temperature by 1, 2, 3 and 4°C resulted in deviations from expected yield of -14%, -28%, -38% and -46% for barley and -17%, +4%, +43% and +113% for wheat.

In the Swat and Chitral districts of Pakistan (mountainous areas with average altitudes of 960 and 1500 m above sea level, respectively), there were mixed results as well (Hussain and Mudasser, 2007). Projected temperature increases of 1.5 and 3 °C would lead to wheat yield declines (by 7% and 24% respectively) in Swat district but increases (by 14% and 23%) in Chitral district. If precipitation increases by 5–15% during the growing season, the study showed a negligible impact on wheat yield. Also in Pakistan, modeling studies show that wheat yields are expected to decline by 6-8 % under B2 and A2 scenarios by the 2080s, whereas rice yields decline by 16-19% under the same conditions (Iqbal et.al. 2009). In India, climate change impacts on sorghum were analyzed using the Info Crop-SORGHUM simulation model (Srivastava *et al.*, 2010). A changing climate was projected to reduce monsoon sorghum grain yield by 2-14% by 2020, with worsening yields by 2050 and 2080. In addition, climate change was projected to reduce winter crop yields up to 7% by 2020, up to 11% by 2050 and up to 32% by 2080. In the Indo-Gangetic Plains, a higher reduction in wheat yields is projected (see below), unless appropriate cultivars and crop management practices are adopted (Ortiz *et al.*, 2008).

In China, modeling studies of the impacts of climate change on crop productivity have had mixed results. Rice is the most important staple food in Asia. Studies show that climate change will alter productivity in China but not always negatively. With rising temperatures, the process of rice development accelerates and reduces the duration for growth. In one study, using the SRES B2 scenario without a CO_2 fertilization effect, the average simulated yield of irrigated rice along the Yangtze River decreased by 14.8%, and the yield of rain-fed rice decreased by 15.2% by 2021–2050 (Shen *et al.*, 2011). With CO_2 fertilization factored in, the simulated yield of irrigated rice decreased by 3.3% and the yield of rain-fed rice decreased by 4.1% on average. Tao *et al.* (2008) reported similar findings using all 20 combinations of four scenarios (A1F1, A2, B2, B1) and five GCMs (HadCM3, PCM, CGCM2, CSIRO2, ECHAM4). Without CO_2 fertilization effects, the growing period would be shorter and yield would decrease. The median values of yield decrease ranged from 6.1% to 18.6%, 13.5% to 31.9%, and 23.6% to 40.2% for air temperature increases of 1, 2, and 3 °C, respectively. However, if CO_2 fertilization effects were included, the median values of yield changes ranged from -10.1% to 3.3%, -16.1% to 2.5%, and -19.3% to 0.18% for the same temperature increases. Other studies have also shown that higher temperature would seriously lower rice yields due to shorter crop duration (Xiong *et al.*, 2010; Yao *et al.*, 2007).

In contrast, Zhang *et al.* (2010) reported that rice yield responses to temperature were broadly positive, which means that yields were not limited by an increase in minimum, maximum or mean temperatures. The authors hypothesize that solar radiation level is the major climatic driver for yield fluctuations at these Chinese experimental stations, and the positive yield correlation to temperature can be explained by the correlations between radiation and temperature, which were positive at most studied stations. Thus, the positive effect of radiation on rice yield overwhelmed temperature's negative effect.

Wassman *et al.* (2009a, 2009b) provide the most comprehensive review of climate change impacts and adaptation for rice in the region. A key conclusion of the report is that, in terms of risks of increasing heat stress, there are parts of Asia where current temperatures are already approaching critical levels during the susceptible stages of the rice plant. These include: Pakistan/North India (October), South India (April, August), East India/Bangladesh (March-June), Myanmar/Thailand/Laos/Cambodia (March-June), Vietnam (April/August), Philippines (April/June), Indonesia (August) and China (July/August).

There have also been simulation studies for other crops in China. In the Huang-Huai-Hai Plain, China's most productive wheat growing region, modeling indicated that winter wheat yields would increase on average by 0.2 Mg ha-1 in 2015-2045 and by 0.8 Mg ha-1 in 2070-2099, due to warmer nighttime temperatures and higher precipitation, under A2 and B2 scenarios using the HadCM3 model (Thomson *et al.*, 2006). Yields were positively influenced by increasing precipitation projected under the climate change scenarios, with the highest average yields in the 2085 time period when the precipitation increase was greatest. Liu *et al.* (2010c) worked on a wheat-maize cropping system in the same plain. Generally, climate change (2 and 5ºC increase in temperature; precipitation increasing and decreasing by 15 and 30%; atmospheric CO_2 enrichment to 500 and 700 ppmv) would result in a mean relative yield change (RYC in %) of −10.33% with a standard deviation of 20.27%, and the lowest and highest RYC values of −46% and +49%. However when CO_2 fertilization effects were included, a positive change in RYC was obtained. In addition, increasing precipitation mitigates the negative impact of increasing temperatures on yield. On average, without CO_2 enrichment, the mean RYC for irrigated land is less negative (−18.5±12.6%) than for rainfed land (−21.5±14.2%), but with CO_2 enrichment there was no significant difference between irrigated and rainfed yields. These results show that CO_2 enrichment reduces the impact of irrigation.

The potential climate change impacts on the productivity of five major crops (canola, corn, potato, rice, and winter wheat) in eastern China have also been investigated using the RegCM3 regional climate model under the A2 scenario (Chavas *et al.*, 2009). Aggregate potential productivity (i.e. if the crop is grown everywhere) with CO_2 fertilization increased 6.5% for rice, 8.3% for canola, 18.6% for corn, 22.9% for potato, and 24.9% for winter wheat, although with significant spatial variability for each crop. However, without the enhanced CO_2-fertilization effect, potential productivity declined in all cases, by 2.5-12%.

Extreme weather events are expected to negatively affect agricultural crop production (IPCC, 2012; Handner *et al.*, 2012). For example, extreme temperatures could lower yields of rice (Tian *et al.*, 2010; Mohammed and Tarpley, 2009). With higher precipitation, flooding could also lead to lower crop production [SREX Ch. 4]. For example, cyclone Sidr which hit Bangladesh in 2007 caused more than 3,000 deaths and the damage to agriculture was estimated to be in excess of US$3 billion (Paul, 2009; Islam *et al.*, 2011; Hasegawa, 2008). Another example is from the Philippines which lies in the typhoon belt with an average of 20 tropical cyclones per year in addition to other extreme weather events (Yumul *et al.*, 2011; Yumul *et al.*, 2010). One study showed that relative losses per crop as part of the annual farm household income due to one tropical cyclone for yellow corn, banana, and rice were 64%, 24%, and 27%, respectively (Huigen and Jens, 2006).

Farming systems and crop areas. Since AR4 [WG2 AR4 10.4.1.2], more information is available on the impacts of climate change on farming systems and cropping areas in more countries in Asia and especially in Central Asia. In general, recent studies validate the northward shifts of crop production with current croplands under threat from the impacts of climate change as mentioned in AR4.

Climate change threatens the food security of West Asia where most of drylands are comprised of rangelands (Thomas, 2008). The region has the world's lowest rate of renewable water resources per capita and is already the major grain importing region of the world. Climate change will exacerbate existing threats to food production and security such as high population growth rates, water scarcity, and land degradation.

In Central Asia, changes in temperature and precipitation regimes could to lead to changes in the area suitable for rain-fed production of cereals and other food crops, changing sustainable stocking rates, and modifications of crop irrigation requirements (Lioubimtseva and Henebry, 2009). The region is expected to become warmer during the coming decades and increasingly arid, especially in the western parts of Turkmenistan, Uzbekistan, and Kazakhstan. The impacts on food production will vary by country. Some parts of the region could be winners (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters and slight increase in winter precipitation), while others could be losers (particularly western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect cotton production, increase already extremely high water demands for irrigation, and exacerbate the already existing water crisis and human-induced desertification). In addition Central Asia and the Caucasus is the second most vulnerable region of the world to crop loss by pollinator loss (Christmann and Aw-Hassanb, 2011). Honey bees (*Apis mellifera*) are important in crop pollination, but bees are highly sensitive to change of temperatures and can provide service only on sunny, warm, dry and not too windy days. The tolerance of local honey bees to climate change needs further elucidation.

In India, the Indo-Gangetic Plains are under threat of a significant reduction in wheat yields (Ortiz *et al.*, 2008). This area produces 90 million tons of wheat grain annually (about 14-15% of global production). Climate projections based on a doubling of CO_2 using a CCM3 model downscaled to a 30 arc-second resolution as part of the Worldclim data set showed that there will be a 51% decrease in the most favorable and high yielding area due to heat stress. About 200 million people (using the current population) whose food intake relies on crop harvests would experience adverse impacts.

In Sri Lanka, a number of studies reviewed by Eriyagama *et al*. (2010) showed varying results. Tea cultivation at low and mid-elevations is more vulnerable to the adverse impacts of climate change than at high elevations. Projected coconut production after 2040 in all climate scenarios will not be sufficient to meet local consumption. The total impact on agriculture (rice, tea, rubber and coconut) production ranges from a decrease of US$96.4 million (-20%) to an increase of US$342 million (+72%) depending on the climate scenarios.

In eastern China, a study showed corn and winter wheat production would benefit significantly from climate change in the North China Plain (Chavas *et al*., 2009). Rice would remain dominant in the southeast but emerges in the northeast, potato and corn yields would become viable in the northwest, and potato yields suffer in the southwest. The study defined vulnerable and emergent regions under future climate conditions as those having a greater than 10% decrease or increase in productivity, respectively.

Rice growing areas are also expected to shift with climate change throughout the region. In Japan, increasing water temperature (1.6–2.0 °C) could lead to a northward shift of the isochrones of safe transplanting dates for rice seedlings (Ohta and Kimura, 2007). As a result, rice cultivation period will be prolonged by approximately 25–30 days. This will allow greater flexibility in the cropping season than at present, resulting in a reduction in the frequency of cool-summer damage in the northern districts. Iizumi *et al*., (2007) assesses the potential reduction of cool-summer damage in northern Japan and supports this conclusion. In addition, ensemble-based probabilistic assessments for rice-yield in Japan are available from Iizumi *et al*., (2011) and Okada *et al*., (2011).The latter paper assesses the impacts on both rice yield and eating quality.

In Indonesia, a marked increase in the probability of a 30-day delay in monsoon onset in 2050 is projected, as a result of changes in the mean climate, from 9-18% today (depending on the region) to 30-40% at the upper tail of the distribution (Naylor *et al*. 2007). In addition, there would be an increase in precipitation later in the crop year (April-June) of around 10% but a substantial decrease (up to 75% at the tail) in precipitation later in the dry season (July-September). However, the increase in April-June rainfall would not compensate for reduced rainfall later in the crop year, particularly if water storage for agriculture was inadequate. Secondly, the extraordinarily dry conditions in July-September could preclude the planting of rice and all other crops without irrigation during these months by 2050. In Sri Lanka, studies on future rice production have had mixed results. A study reviewed by Eriyagama *et al*., 2010 showed that a 0.1-0.5°C increase in temperature could depress rice yield by approximately 1-5%. However, another study suggested that rice yields will respond positively (increases of 24 and 39% in the two seasons) to elevated CO_2 even at higher growing temperatures (>30°C) in subhumid tropical environments. The real threat to rice cultivation might be changes in the amount of precipitation and its temporal distribution. Climate change is expected to affect water supply for rice cultivation in Sri Lanka (De Silva *et al*., 2007). During the wet season, impacts on irrigated rice production are projected to be positive in the extreme south of the country, confirming results of a previous study. However, the impacts will be negative across most of Sri Lanka. During the wet season, average rainfall would decline by 17% (A2) and 9% (B2), with rains ending earlier. Consequently, the average paddy irrigation water requirement would increase by 23% (A2) and 13% (B2).

Similarly in the whole of China, Xiong *et al*. (2010) reported there would be insufficient water for agriculture in the 2020s and 2040s, due to increases in water demand for non-agricultural uses, using the HadAM3H GCM and the PRECIS regional model, especially under the A2 scenario (see also 24.4.1.3). The proportion of water demanded by rice (which consumes 79% of the total baseline potential water demand of three grain crops) is projected to increase, because of significant increases in the projected water demand by rice under A2 (+62% for the 2020s above the baseline, and +58% for the 2040s), and moderate increases under B2 (5% and 2% for the 2020s, and the 2040s, respectively). However, due to increases in demand in other sectors (domestic, environmental and industrial) captured in the socio-economic scenarios (SES), the water available for agriculture decreases dramatically under A2 by 5% (2020s) and 21% (2040s) and under B2 by 3% (2020s) and 16% (2040s).

High quality fruits are cultivated in a narrow temperature zone. In Japan, the current main apple producing districts have annual mean temperature of 6-14°C with mean temperature of 13-21°C from April to October. Many parts of these districts may become unfavorable for apple cultivation by the 2060s (Sugiura *et al*., 2005).

Fisheries and aquaculture. Asia dominates the global production of food from both capture fisheries and aquaculture, with China, Indonesia, India, the Philippines and Myanmar in the top ten for capture fisheries and China, India, Vietnam, Indonesia, Thailand, Bangladesh, the Philippines and Japan in the top ten for aquaculture (FAO 2010). More than half of the global marine fish catch in 2008 was in the West Pacific and Indian Ocean, and the lower Mekong River basin supports the largest freshwater capture fishery in the world. Fish production is also a vital component of regional livelihoods, with 85.5% of the world's fishers (28 m) and fish farmers (10 m) in Asia in 2008. Many more people engage in capture fisheries part-time. Fish catches in the Asian Arctic are relatively small, but are important for local cultures and regional food security (Zeller *et al.* 2011).

Inland fisheries will continue to be vulnerable to a wide range of on-going threats, including overfishing, habitat loss, water abstraction, drainage of wetlands, pollution, and dam construction, making the impacts of climate change hard to detect. Most concerns have centered on rising water temperatures and the potential impacts of climate change on flow regimes, which in turn are expected affect the reproduction of many fish species (Allison *et al.*, 2009; Barange and Perry, 2009; Bezuijen, 2011; Dudgeon, 2011; see also section 24.4.2.3). Sea-level rise is expected to impact both capture fisheries and aquaculture production in river deltas (De Silva and Soto, 2009). For marine capture fisheries, Cheung et al. (2009, 2010) used a dynamic bioclimate envelope model to project the distributions of 1066 species of exploited marine fish and invertebrates for 2055, based on the SRES A1B scenario. This analysis suggests that climate change may lead to a massive redistribution of fisheries catch potential, with large increases in high-latitude regions, including Asian Russia, and large declines in the tropics, particularly Indonesia. Other studies have made generally similar predictions, with climate change impacts on marine productivity expected to be large and negative in the tropics, in part because of the vulnerability of coral reefs to both warming and ocean acidification (see also section 24.4.3.3), and large and positive in arctic and subarctic regions, because of sea-ice retreat and poleward species shifts (Doney *et al.*, 2012; Sumaila *et al.*, 2011; Blanchard *et al.*, 2012). Predictions of a reduction in the average maximum body weight of marine fishes by 14-24% are an additional threat to fisheries (Cheung et al., 2012). Studies on the economically important yellowtail in Japanese waters have shown a northward extension in the winter distribution during the warm 1990s and project a 3^{o} northward shift in latitude by 2050 under the A1B scenario (Tian *et al.*, 2012). Similarly, the important Pacific saury is expected to shift its range polewards by $< 6^{o}$ (Tseng *et al.*, 2011)

Future food supply and demand. AR4 Section 10.4.1.4 was largely based on global models that included Asia. There are now several quantitative studies of both the whole continent and individual countries. In general, these show that the risk of hunger, food insecurity and loss of livelihood due to climate change will be high, as discussed below.

Rice is a key staple crop in Asia and 90% or more of the world's production is from Asia. An Asia-wide study revealed that climate change scenarios (using 18 GCMs for A1B; 14 GCMs for A2 and 17 GCMs for B1) would reduce rice yield over a large portion of the continent (Masutomi *et al.*, 2009). The most vulnerable regions were western Japan, eastern China, the southern part of the Indochina peninsula, and the northern part of South Asia. In these areas, a rise in temperature during the growing periods would be the main cause of the decreases in yield. The negative impacts of climate change were diminished, but not totally eliminated, by the positive effect of CO_2 fertilization. In a global study, Hertel *et al.* (2010) showed that under the low-productivity scenario (due to climate change), prices for major staples would rise 10–60% by 2030 in Asia. Poverty rates in some non-agricultural household could rise by 20–50% in parts of Asia and fall by significant proportions for agriculture households.

In Russia, climate change may also lead to "food production shortfall", which was defined as an event in which the annual potential (i.e. climate-related) production of the most important crops in an administrative region in a specific year falls below 50% of its climate-normal (1961–1990) average (Alcamo *et al.*, 2007). The frequency of shortfalls in the main crop growing regions is around 2 years/decade under climate baseline conditions, but could climb to 5–6 years/decade in the 2070s (using the ECHAM and HadCM3 models and the A2 and B2 scenarios). The increasing shortfalls were attributed to severe droughts. The study estimated that the number of people living in these regions may grow to 82–139 million in the 2070s. Increasing frequency of extreme climate events will pose an increasing threat to the security of Russia's food system.

Tchebakova *et al*., (2010) analyzed the agroclimatical potential of Central Siberia in the 21st century. They concluded that climate changes to come for the years 2020 and 2080 (HadCM3 with B1 and A2 scenarios) will in general be beneficial for this territory. “From 50 to 85% of Central Siberia is predicted to be climatically suitable for agriculture by the end of the century, and only soil potential would limit crop advance and expansion to the North. Crop production could increase twofold. Future Siberian climatic resources could provide the potential for a great variety of crops to grow that previously did not exist in these lands.” (Tchebakova *et al*., 2010).

Most of the studies reviewed in the previous sections predict negative impacts of climate change on crop yield and therefore presumably on food supply. Climate change may also lead to an increase in food supply in some countries. For example, climate change may provide a windfall for wheat farmers in parts of Pakistan. Warming temperatures would make it possible to grow at least two crops (wheat and maize) a year in the mountain areas (Hussain and Mudasser, 2007). It will also allow more time for land preparation for the subsequent maize crop, with beneficial effects on yield. The increased productivity of the wheat–maize cropping system is expected to improve food security, increase farm income and reduce overall poverty of the farm households in the area.

Pests and diseases. AR4 contained a generalization about the possibility of increasing pests and diseases due to climate change. Since then there have been very few studies of climate change impacts on pests and diseases which support this conclusion. For example in South Asia, warming temperatures could lead to higher incidence of spot blotch (caused by *Cochliobolus sativus*), already a serious constraint on wheat production at present. An increasing mean minimum temperature in March showed a positive relationship with spot blotch severity (Sharma *et al*., 2007). Sharma *et al*. (2010) recommended the regular monitoring of pest populations in future to determine if a threshold has been exceeded and if control measures are required. This information will also be valuable for forecasting pest populations, severity of damage, and pest outbreaks. Climate change may also modify the effectiveness of biological control (e.g. natural enemies), biopesticides, and synthetic insecticides.

24.4.4.5. Adaptation Options

Since AR4, there have been additional studies of recommended and potential adaptation strategies and practices in Asia (see Table 24-7) and there is new information for West and Central Asia. There are also many more crop-specific and country-specific adaptation options available.

[INSERT TABLE 24-7 HERE
Table 24-7: Summary of adaptation options for agriculture in Asia.]

Farmers have been adapting to climate risks for generations. Indigenous and local adaptation strategies have been documented for Southeast Asia (Peras *et al*., 2008; Lasco *et al*., 2011; Lasco *et al*., 2010) and could be used as a basis for future climate change adaptation. Social and institutional aspects of climate change adaptation have also been investigated in the Philippines. Agent-based modeling showed that smallholder farmers face a number of constraints in adapting new technologies to cope with climate risks (Acosta-Michlik and Espaldon, 2008). In general, lack of knowledge and money were the most important reasons for not adopting drought-related technical measures. In the above studies there are many non-farm related adaptation strategies, such as selling valuables, sending family workers to work overseas, and migrating to another location. Local government units can also play a catalytic role in climate change adaptation as shown by the experience of Albay province in the Philippines, which has been in the forefront of climate change adaptation activities in the country (Lasco *et al*., 2013; Lasco *et al*. 2008). The main initiatives include legislating local policies on climate change adaptation, integrating climate change adaptation and disaster risk management, and the implementation of on-the ground activities. In addition, they have become a national player in climate change adaptation in the Philippines.

24.4.5. Human Settlements, Industry, and Infrastructure

24.4.5.1. Sub-Regional Diversity

Asia, being the largest continent in the world in terms of area and population, is both diverse and complex. Sustainable development will be challenged as climate change compounds the pressures that rapid urbanization, industrialization and economic development have placed on natural, social and economic resources (IPCC, 2007b). Settlement patterns, urbanization and changes in socioeconomic conditions greatly influence trends in exposure and vulnerability to climate extremes (IPCC, 2012). Population distribution is uneven within Asia, with two subregions, East Asia and South-Central Asia, accounting for 80% of the total (UNFPA, 2010). Moreover, a few Asian countries account for 69% of the world's rural population, with India and China alone accounting for 45%, followed by Bangladesh, Indonesia and Pakistan, each with over 100 million rural inhabitants. Much of the increase projected for the world population is expected to come from 39 high-fertility countries, of which nine are located in Asia. Although population growth rates have been decreasing in almost all subregions of Asia since 2000 (UN ESCAP, 2011), growth continues to be high, particularly in countries with low human development performance, leading to large populations with limited adaptive capacity (World Bank 2012).

Notwithstanding considerable challenges in measurement (Satterthwaite 2006), around one in every five urban dwellers in Asia lives in large urban agglomerations and almost 50% of urban dwellers live in small cities (UN, 2012). However, there is wide subregional variation. For example, North and Central Asia are the most urbanized areas, with over 63% of the population living in urban areas, with the exception of Kyrgyzstan and Tajikistan, followed by East and Northeast Asia, where rapid urbanization in the last two decades has led to half the population living in cities (UN ESCAP, 2011; UN Habitat, 2010). South and Southwest Asia are the least urbanized subregions, with only a third of their populations living in urban areas. However, these regions have the highest urban population growth rates within Asia at an average of 2.4% per year during 2005-2010 (UN-ESCAP, 2011). By the middle of this century, Asia's urban population will increase by 1.4 billion and will account for over 50% of the global population, with China and India projected to account for about a third of the increase in the coming decades (UN, 2012).

Most Asian countries are witnessing significant development opportunities as well as a myriad of challenges. In 2010, seven Asian economies (China, India, Indonesia, Japan, Korea, Malaysia and Thailand) shared 78% of Asia's population and 87% of Asia's GDP (ADB, 2011). However, across all the subregions of Asia, poor people and urban slum dwellers tend to live in high-risk areas, such as unstable slopes and flood plains, and often cannot afford well-built houses. The poorest people are expected to suffer the most from climate change (UN-Habitat, 2011).

24.4.5.2. Observed Impacts

Asia has in the past suffered from many disasters related to natural hazards (IPCC, 2012). The data also reveals a strong increase in loss and damage caused by such disasters over recent years (Munich Re 2011; CRED 2012). However, the literature suggests that this increase can be attributed to climate change only with low confidence [18.4.1]. Asia experienced the highest number of weather- and climate-related disasters in the world during the period 2000-2008 and suffered huge economic losses, accounting for the second highest proportion (27.5%) of the total global economic loss. Losses of human lives, cultural heritage, and ecosystem services are difficult to value and monetize, and thus are poorly reflected in estimates of monetary losses. Impacts on the informal or undocumented economy, as well as indirect effects, can also be very important in some areas and sectors, but are generally not counted in reported estimates of losses (IPCC, 2012).

Flood mortality risk is heavily concentrated in Asia. The top ten countries, based on numbers of lives lost, are India, Bangladesh, China, Vietnam, Cambodia, Myanmar, Sudan, Korea, Afghanistan and Pakistan (UNISDR, 2009). Severe floods in Mumbai in 2005 following 944 mm rainfall within 24 hours have been attributed to both climatic factors and non-climatic factors, such as lack of early warning, preparedness and response capacities at the local level, lack of modern rain gauges, poor urban drainage systems, blockages in the natural drainage channels, poor waste management, poor urban planning, lack of civic sense among citizens, among others (IPCC, 2012; Surjan *et* *al*., 2009). Yet, despite the increasing number of people living in floodplains, strengthening of capacities to address the mortality risk associated with major weather-related hazards, such as floods, has resulted in a downward trend in mortality risk relative to population size, as in East Asia, where mortality risk is now at a third of its 1980 level (UNISDR, 2011). Note also that many areas of Asia have seasonal shortfalls in the availability of water, which is also a growing crisis (ADB *et al*., 2012).

24.4.5.3. Projected Impacts

A large proportion of Asia's population lives in low elevation coastal zones that are particularly at risk from climate change hazards, including sea-level rise, storm surges and typhoons [5.3.2.1; 8.2.2.5; Box CC-TC]. Human settlements include rural villages, small and mid-sized cities, megacities and periurban fringes, but most attention in terms of projected climate change impacts has been given to Asia's urban areas, particularly to megacities. Depending on the region, half to two-thirds of Asia's cities with 1 million or more inhabitants are exposed to one or even multiple hazards, with floods and cyclones being the most important ones (UN, 2012). The risk of underestimating the impact of rare or more severe natural disasters on urban areas is high. Asian mega-deltas are particularly susceptible to extreme impacts due to a combination of high-hazard river, coastal flooding and increased population exposure from expanding urban areas with large proportions of high vulnerability groups (IPCC, 2012).

Floodplains. Three of the world's five most populated cities (Tokyo, Delhi and Shanghai) are located in areas with high risk of floods (UN, 2012). Flood risk and associated human and material losses are heavily concentrated in India, Bangladesh, and China. At the same time, the East Asia region in particular is experiencing increasing water shortages, affecting its socioeconomic, agricultural, and environmental conditions negatively, which is attributed to lack of rains and high evapotranspiration, as well as over-exploitation of water resources. Any increase in climatic and weather extremes is expected to aggravate the problem of pollution and flooding. Aging infrastructure may hinder the operation of sewer systems, particularly in Central Asia (IPCC, 2012).

Coastal Areas. By the year 2025, 70% of Asia's urban population will live in the coastal areas, with the majority located in low-elevation coastal zones (Balk *et al*., 2009). Climate change is expected to increase the risk of cyclones, flooding, landslides and drought, the adverse events which have a direct influence on urban and rural settlements, infrastructure and industries alike. Large parts of South, East and Southeast Asia are exposed to a high degree of cumulative climate-related risk (UN-Habitat, 2011). Asia has more than 90% of the global population exposed to tropical cyclones (IPCC, 2012; see Box CC-TC). Damage due to storm surge is sensitive to any change in the magnitude of tropical cyclones. For example, projections for the inner parts of three major bays (Tokyo, Ise, and Osaka) in Japan indicated that a typhoon that is 1.3 times as strong as the design standard, combined with a sea-level rise of 60 cm, would cause damage costs of about US$3, 40, and 27 billion, respectively, in the investigated bays (IPCC, 2012; Suzuki, 2009).

Exposure of the world's large port cities (population exceeding 1 million inhabitants in 2005) to coastal flooding due to sea-level rise and storm surge now and in the 2070s have been estimated, taking into account scenarios of socio-economic and climate changes. About 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population in the cities considered) are currently exposed to a 1 in 100 year coastal flood event (Hanson *et al*. 2011). The bulk of exposed assets in Asia are currently concentrated in Japan, where 46% of the population, 47% of industrial production and 77% of commercial sales are concentrated in ocean-front cities, towns and villages (Yasuhara, *et al*., 2011). Mumbai, Kolkata, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, and Hai Phòng will be the cities with the greatest population exposure to coastal flooding in 2070 (IPCC, 2012). Port authorities from around the world perceive sea-level rise as an issue of great concern (Becker *et al*., 2012). There is consensus that planned rapid expansion of ports should take into account adaptation measures as the new infrastructure may still be in use at the end of the century.

Population and Assets. Asia has a large – and rapidly expanding – proportion of the global urban exposure and vulnerability related to climate change hazards [SREX 4.4.3]. By the 2070s, the top Asian cities in terms of population exposure (including all environmental and socioeconomic factors) are expected to be Kolkata, Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, and Hai Phòng (Nicholls *et al*., 2008). The top Asian cities in terms of assets exposed included Guangdong, Kolkata, Shanghai, Mumbai, Tianjin, Tokyo, Hong Kong, and Bangkok. Hence, cities in Asia, particularly those in China, India and Thailand, become even more dominant in terms of population and asset exposure, as a result of the rapid urbanization and economic growth expected in these countries. This study also estimates that by 2070, population and asset exposure within Asia's large port cities will be disproportionately concentrated in China, India, Japan, Thailand, Vietnam, Bangladesh, Myanmar and Indonesia (Nicholls *et al*., 2008). Vulnerability and potential impacts in Asia's small and medium sized cities is less understood despite their demographic importance (see above). This is partially due to questions around measurement and administrative definitions (Satterthwaite, 2006).

In line with the rapid urban growth and sprawl in many parts of Asia, the periurban interface between urban and rural areas deserves particular attention when considering climate change vulnerability (see also chapter 18.4.1). Garschagen et al. (2011) find, for example, that periurban agriculturalists in the Vietnamese Mekong Delta are facing a multiple burden since they are often exposed to overlapping risks resulting from (a) socio-economic transformations, such as land title insecurity and price pressures; (b) local biophysical degradation, as periurban areas serve as sinks for urban wastes; and (c) climate change impacts, as they do not benefit from the inner-urban disaster risk management measures. Nevertheless, the periurban interface is still underemphasized in studies on impacts, vulnerability and adaptation in Asia. Settlements on unstable slopes or landslide-prone areas face increased prospects of rainfall-induced landslides (IPCC, 2012).

Water-scarcity, especially in summer, is now beyond the control of local governments in urban areas in a number of cities and towns in Asia. Groundwater sources, which are affordable means of high-quality water supply in cities of developing countries, are threatened due to over-withdrawals. Aquifer levels have fallen by 20-50 meters in cities such as Bangkok, Manila and Tianjin and between 10 and 20 meters in many other cities (UNESCO, 2012). The drop in groundwater levels often results in land subsidence, which can enhance hazard exposure due to coastal inundation and sea-level rise especially in settlements near the coast, and deterioration of groundwater quality. Cities susceptible to human-induced subsidence (mainly, developing country cities in deltaic regions with rapidly growing populations) could see significant increases in exposure (Nicholls *et al*., 2008).

Industry and Infrastructure. The impacts of climate change on industry include both direct impacts on industrial production and indirect impacts on industrial enterprises due to the implementation of mitigation activities (Li, 2008). The impact of climate change on infrastructure deterioration cannot be ignored, but can be addressed by changes to design procedures, including increases in cover thickness, improved quality of concrete, and coatings and barriers (Stewart *et al*., 2012). Climate change and extreme events may have a greater impact on large and medium-sized construction projects (Kim, 2007).

In July 2005, across Northwest India, the flooding affected an area of over 35,500 km^2, affecting 20 million people and causing economic damages of around US$3–5 billion (Swiss Re, 2006; Munich Re, 2006). Estimates suggest that by upgrading the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70%, and through extending insurance to 100% penetration, the indirect effects of flooding could be almost halved, speeding recovery significantly (Ranger, 2011). On the east coast of India, clusters of districts with poor infrastructure and demographic development are also the regions of maximum vulnerability, so extreme events are likely to be more catastrophic in nature for the people living in these districts. Moreover, the lower the district is in terms of the infrastructure index and its growth, the more exposed it is to the potential damage from extreme events and hence people living in these regions are likely to be highly vulnerable (Patnaik, 2009). In 2008, the embankments on the Kosi River (a tributary of the Ganges) failed and the channel shifted by as much as 120 km (Sinha, 2008), displacing over sixty thousand people in Nepal and three and a half million in India. Transport and power systems were disrupted across large areas. However, the embankment failure was not caused by an extreme event but represented a failure of interlinked physical and institutional infrastructure systems in an area characterized by complex social, political, and environmental relationships (Moench, 2010).

Climate change apparently has little influence on general travel decisions for tourism, even though weather extremes such as tropical storms are relevant, as revealed by a case study from Israel (Gossling and Hall, 2006). Tourist perceptions of weather and climate vary widely. Many Asian countries are major tourist destinations and more studies are needed to understand the impact of climate change on tourism. With respect to beach tourism, large developing countries and small islands states may be among the most vulnerable due to high exposure and low adaptive capacity (Perch-Nielsen, 2010). A number of Asian countries were found vulnerable in this regard.

24.4.5.4. Vulnerabilities to Key Drivers

The impacts of climate change on human settlements, industry and infrastructure will not only be due to sea-level rise and extreme weather events. Disruption of basic services such as water supply, sanitation, energy provision, and transportation system have implications for local economies and "strip populations of their assets and livelihoods", in some cases leading to mass migration (UN-Habitat, 2010). Such impacts are not expected to be evenly spread among regions and cities, across sectors of the economy or among socioeconomic groups. They tend to reinforce existing inequalities and disrupt the social fabric of cities and exacerbate poverty.

A study of Chittagong, Bangladesh, concludes that urban adaptation and strengthening of local government capacity to reduce vulnerability of the urban poor is not considered a priority in national climate change adaptation policy (Ahammad, 2011). As a result, those most at risk from climate extremes are not given adequate attention. In addition, unequal access to education, health and other public services not only contribute to an increase in income disparities, but can also increase vulnerabilities to climate extremes. In the last two decades, 11 economies of Asia, accounting for more than four-fifths of the region's population, have experienced a widening gap between rich and poor (ADB, 2012). These development challenges can increase the impacts of climate extremes and undermine opportunities arising from adaptation.

Rapid economic growth in Asia is translating into land-use related changes, faster construction of buildings and infrastructure, and corresponding industrial development. While such development is improving the quality of life, it is also creating more impervious surfaces and thus increasing both the localized heat-island effect as well as flooding in dense urban environments. UN-Habitat (2010) states that "Climate change has direct effects on the physical infrastructure of a city – its network of buildings, roads, drainage, and energy systems – which in turn impact the welfare and livelihoods of its residents". The increasing frequency and intensity of extreme climatic events and slow-onset changes will increase the vulnerability of urban economic assets and subsequently the cost of doing business.

In northern Asia, thawing of permafrost can affect residential buildings, pavements, pipelines used to transport petroleum and gas, pump stations and extraction facilities. Ice roads, an important form of transportation for many northern activities may not be passable when permafrost thaws (Kelmelis, 2011; Smith, 2011; Forbes, 2011; FNCRF, 2010).

24.4.5.5. Adaptation Options

An ADB and UN report estimates that "about two-thirds of the $8 trillion needed for infrastructure investment in Asia and the Pacific between 2010 and 2020 will be in the form of new infrastructure, which creates tremendous opportunities to design, finance and manage more sustainable infrastructure" (ADB, 2012). A recent study estimated that direct and indirect losses for a 1-in-100 year flooding in Mumbai could triple by the 2080s compared with the present (increasing from US$700 to US$2,305 million), and suggests adaptation measures to reduce future damages (Ranger *et al*., 2011). The massive investment required may not be affordable for most of the developing countries of Asia (Zevenbergen and Herath, 2008). Hallegatte *et al*. (2011) suggests that adaptation measures, especially in developing countries, offer a 'no regrets' solution "where basic urban infrastructure is often absent (e.g. appropriate drainage infrastructure), leaving room for actions that both increase immediate well-being and reduce vulnerability to future climate change". Adaptation measures, such as improvements to a city's drainage systems and extending insurance to 100% penetration, can reduce losses associated with a 1-in-100 year flood event by 50-70% (Ranger *et al*., 2011).

The role of urban planning and urban planners in adaptation to climate change impacts has recently been emphasized (IPCC, 2012; Fuchs *et.al*., 2011). City planners with greater understanding of climate change related hazards and capable of communicating associated risks can effectively utilize spatial planning and social infrastructure as tools for adaptation in cities (Fuchs *et.al.*, 2011). Climate-sensitive urban planning is effective as a long-term adaptation measure if it takes into account climate variability, including uncertainty, and systems vulnerability and capacity (IPCC, 2012). Based on a review of governmental adaptation strategies in selected cities (including Ho Chi Minh City and Singapore in Asia), Birkmann *et al.* (2010) argue that a paradigm shift is needed in urban climate change adaptation, away from a focus on solely adapting physical infrastructure, towards also adapting planning, management and governance modes to be able to deal with the uncertainty and the unprecedented challenges implied by climate change. Garschagen and Kraas (2011) call for a stronger consideration of the multiple other challenges for urban governments in line with the comprehensive social, economic and political transformation underway in many of Asia's transition countries and emerging economies. Urban climate change adaptation in Asia cannot be debated without putting these debates into the context of these current and future transformations in the human domain. Institutional and cultural challenges can also emerge when transferring global concepts (e.g. on resilience) to Asia in order to guide the political processes around urban climate change adaptation. This is because the institutional set-up might limit the opportunity for implementing the respective management principles, for example on co-learning, self-organization or bottom-up decision making (Garschagen *et al.*, 2011). Paying particular attention to the national specifics, Revi (2008) suggests a framework for adapting Indian cities to climate change.

Climate change is expected to influence the demand for space cooling and heating (van Vuuren *et al.*, 2011). Air conditioning can reduce vulnerability to heat waves, but the extra energy demand will be in the range 750,000-1,350,000 GWh with a 3.7 °C increase in surface temperatures under different population scenarios and increasing incomes by the year 2100 (Akpinar-Ferranda and Singh, 2010). Green infrastructure has an important role in mitigating the impacts of climate change on urban areas, including reducing energy demand and improving stormwater management (Barber *et al.*, 2009; Gaffin *et al.*, 2012). Urban park systems, street trees, green roofs (Oberndorfer *et al.*, 2007), green walls, permeable pavements and other green infrastructure can improve urban climate and hydrology, while providing ecological and health co-benefits.

A tried method for adapting pavements, railroads, and oil and gas pipelines for the thawing of permafrost is thermal stabilization. Monitoring the buildings' basements and their timely stabilization is the main adaptation measure for residential and industrial buildings. Projected changes in permafrost should be considered by planners of new infrastructure, residential and industrial buildings. A key component of informing policy and decision-making is quantitative scientific research concerning past, present, and future permafrost changes and impacts (FNCRF, 2010; Anisimov *et al.*, 2010; Forbes *et al.*, 2011).

24.4.6. Human Health, Security, Livelihoods, and Poverty

24.4.6.1. Sub-Regional Diversity

Asia is predominantly an agrarian society as is evident from 58% of its total population living in rural areas, out of which 81.8% are dependent on agriculture for their livelihoods (FAOSTAT, 2011). In addition, agriculture employs 24.7% of the total population in these countries and contributes 15.3% of the total value-added GDP (FAOSTAT, 2011; World Bank, 2011). Asia also has high levels of rural poverty compared to urban poverty, with relatively higher poverty incidence in the eight least developing countries in the region (FAOSTAT, 2011). The high incidence of rural poverty and hunger is closely related to heavy dependence on natural resources that are directly influenced by changes in weather and climate, indicating a close connection between rural livelihoods and poverty (IFAD, 2010; Haggblade *et al.*, 2010).

Although Asia has emerged as an economic power during recent decades, there is still a considerable gap in progress in developmental indicators when compared to rest of the world (World Bank, 2011). In terms of these indicators, Southeast Asia is the third poorest region in the world after Sub-Saharan Africa and Southern Asia, and ranks poorly in terms of labor productivity, access to food, maternal health, and forestation (UN, 2009). Consequently, as a large proportion of rural populations depend on agriculture, agriculture has been identified as a key driver of economic growth in the region (World Bank, 2007).

Impacts on human security in Asia will primarily manifest through direct and indirect impacts on water resources, agriculture, coastal areas, resource-dependent livelihoods and on urban settlements and infrastructure, with implications for human health and well-being. To a large extent, regional disparities on account of socio-economic context and geographical characteristics among others, define the differential vulnerabilities and impacts within countries in Asia (Sivakumar and Stefanski 2011; Thomas, 2008).

24.4.6.2. Observed Impacts

Floods and health. Epidemics have been reported in the aftermath of floods and storms (Bagchi, 2007) due to decreased drinking water quality (Harris *et al*., 2008; Hashizume *et al*., 2008; Kazama *et al*., 2012; Solberg, 2010), proliferation of mosquitos (Pawar *et al*., 2008), exposure to rodent-borne pathogens like hantavirus and leptospira (Kawaguchi *et al*., 2008; Zhou *et al*., 2011) and to intermediate host snails of shistosoma (Wu *et al*., 2008). Contaminated flood waters in urban environments have caused exposure to pathogens and toxic compounds, as noted in for example India and Pakistan (Sohan *et al*., 2008; Warraich *et al*., 2011). Mental disorders and posttraumatic stress syndrome are also observed in disaster prone areas (Li *et al*., 2010; Udomratn, 2008), and have in India been linked to age and educational level (Telles *et al*., 2009).

Heat and health. The effects of heat on mortality and morbidity, mainly in terms of hospital admission, have been studied in many countries throughout Asia, with a specific focus on effects among the elderly and persons with cardiovascular and respiratory disorders (Guo *et al*., 2009; Huang *et al*., 2010; Kan *et al*., 2007). Associations between temperature rise and mortality have been shown for India, Thailand (McMichael *et al*., 2008) and several cities in East Asia, including Japan, South Korea, China and Taiwan (Chung *et al*., 2009; Kim *et al*., 2006). Several studies have analyzed the health effects of air pollution in combination with increased temperatures (Lee *et al*., 2007; Qian *et al*., 2010; Wong *et al*., 2010; Yi *et al*., 2010). Intense heat waves have also been shown to affect outdoor workers in South and East Asia (Hyatt *et al*., 2010; Nag *et al*., 2007).

Drought and health. Prolonged drought in combination with windy conditions increases the exposure to sand and dust, often mixed with toxic compounds (Wang *et al*., 2011d). There are indications that dust storms in South West, Central and East Asia increase hospital admissions and worsen asthmatic conditions, as well as causing skin and eye irritations (Griffin *et al*., 2007; Hashizume *et al*., 2010; Kan *et al*., 2012; Tam *et al*., 2012). Prolonged drought may also lead to wildfires and haze exposure, with increased morbidity and mortality, as observed in Southeast Asia (Johnston *et al*., 2012). Drought can also cause disruption of food security that leads to increases of malnutrition (Kumar *et al*., 2005), and consequently increase susceptibility to infectious diseases.

Water-borne diseases. Many pathogens and parasites multiply faster at higher temperatures. Increases in temperatures have been correlated with outbreaks of water-borne diseases in for example East Asia (Huang *et al*., 2008; Onozuka *et al*., 2010¸ Zhang *et al*., 2007). Other studies from South and East Asia have shown a correlation between diarrheal outbreaks and a combination of higher temperatures and heavy rainfall (Chou *et al*., 2010; Hashizume *et al*., 2007; Majra and Gur, 2009). Increasing coastal water temperatures have been correlated with outbreaks of systemic *Vibrio vulnificus* infection in Israel (Paz *et al*., 2007) and Taiwan (Kim and Jang, 2010). Cholera outbreaks in coastal populations in South Asia have been associated with increasing water temperatures and algal blooms (Huq *et al*., 2005). More distal climate modes, such as El Niño and the Indian Ocean Dipole, that arise from ocean-atmosphere interactions in the tropical Pacific and Indian Ocean, respectively, have been associated with cholera epidemics in Bangladesh (Pascual *et al*., 2000; Rodó *et al*., 2002; Hashizume *et al*., 2011)

Vector-borne diseases. Increasing temperatures affect vector-borne pathogens during the extrinsic incubation period and shorten the life-cycles of vectors, thereby facilitating larger vector populations and enhanced disease transmission, whilst vector's ability to acquire and maintain a parasite/pathogen tails off at higher temperatures (Paaijmans *et al*., 2012). Several Asian studies have focused on the emergence of dengue fever. Outbreaks have been correlated with temperature and rainfall with varying time lags (Sriprom *et al*., 2010; Hsieh and Chen 2009, Nitatpattana *et al*., 2008; Shang *et al*., 2010; Su, 2008; Hii *et al*., 2009; Hashizume *et al*., 2012). Outbreaks of the vaccine-preventable Japanese encephalitis have been linked to rainfall in studies from the Himalayan region (Bhattachan *et al*., 2009; Patridge *et al*., 2007), and to a combination of rainfall and temperatures in South and East

Asia (Bi *et al*., 2007; Murty *et al*., 2010). Malaria prevalence is often influenced by other factors than climate variability, but studies from India and Nepal have found correlations with rainfall (Dahal, 2008; Dev and Dash, 2007; Devi and Jauhari, 2006; Laneri *et al*., 2010), whereas temperature was linked to malaria distribution and seasonality in Saudi Arabia (Kheir *et al*., 2010). The re-emergence of malaria in central China has been attributed to rainfall and increases in temperature close to water bodies (Zhou *et al*., 2010). Temperature, precipitation, and the virus-carrying index among rodents have been found to be correlated with the prevalence of hemorrhagic fever with renal syndrome in China (Guan *et al*., 2009; Yan *et al*., 2008).

Livelihoods and Poverty. There have been significant changes in terms of livelihood diversification in Asia over recent decades due to rapid economic development (see Table 24-5). Estimates suggest that currently about 51% of total income in rural Asia comes from non-farm sources (Haggblade *et al*., 2010; Haggblade *et al*., 2009), out of which a major proportion comes from local non-farm business and employment. There has also been steady growth in the proportion of remittances contributing to rural income (Estudillo and Otsuka, 2010). Asia has made significant improvements in poverty eradication over the past decade (World Bank, 2008). At the subregional level, East Asia has recorded a rapid reduction in poverty, followed by South Asia (IFAD, 2010). A significant part of the reduction has come from population shifts, rapid growth in agriculture, and urban contributions (Janvry and Sadoulet, 2010). Literature suggests that climate change negatively impacts livelihoods (see Table 24-5) and that these impacts are directly related to natural resources affected by changes in weather and climate. One of the important factors to be considered while evaluating the past impacts of climate change on agriculture is the play of several factors that have made the region's agriculture less sustainable, which include input non-responsive yields, soil erosion, natural calamities, and water and land quality related problems (Dev, 2011). These factors have predisposed the region's livelihoods to climate change vulnerability. Rural livelihoods are more severely impacted than the urban ones due to the predominantly agricultural population and the poor are more vulnerable to livelihood loss.

24.4.6.3. Projected Impacts

Health effects. An emerging interregional public health concern in Asia is increasing mortality and morbidity due to heat waves. An ageing population in Asia will increase the number of people at risk, especially those with cardio-vascular and respiratory disorders. The rapid urbanization and growth of megacities in Asia add to the magnitude of the problem with the urban heat island effect that may increase downtown temperatures considerably compared to surrounding rural areas (Tan *et al*., 2010), even though local adaptation of the built environment and urban planning will define the magnitude of the impacts on public health. The relationship between temperature and mortality often shows a U-shaped curve (Guo *et al*., 2009). Studies from both tropical and temperate environments in Asia show increased mortality in particular in rural environments during cold events, even if temperatures do not fall below 0°C (Hashizume *et al*., 2009; Wu *et al*., 2011). However, some studies on cold-related deaths in developing areas suggest that other factors than climate are important contributors here, and that climate change will not decrease cold-related deaths to any larger extent in such environments (Honda and Ono 2009). Heat stress disorders and consequent productivity loss among workers have also been reported in Asia (Lin *et al*., 2009; Langkulsen *et al*., 2010).

Climate change will affect the local transmission of many climate-sensitive diseases. Increases in heavy rain and temperature are projected to increase the risk of diarrhoeal diseases in for example China (Zhang *et al*., 2008). The impact of climate change on malaria risk will differ between areas, as projected for West and South Asia (Husain and Chaudhary, 2008; Garg *et al*., 2009; Majra and Gur, 2009), whilst a study reported that the impact of socio-economic development is larger than that of climate change (Béguin *et al*., 2011). Some studies have developed climate change-disease prevalence models, for example one for schistosomiasis in China shows an increased northern distribution range of the disease with climate change (Kan *et al*., 2012, Zhou *et al*., 2008). Impacts of climate change on fish production (Qiu *et al*., 2010) is being studied, along with impacts on chemical pathways in the marine environment and consequent impacts on food safety (Tirado *et al*., 2010b), including seafood safety (Marques *et al*., 2010).

Livelihood and Poverty. Floods, droughts and changes in seasonal rainfall patterns are expected to negatively impact crop yields, food security and livelihood in vulnerable areas (Dawe *et al*., 2008; Douglas, 2009; Kelkar *et al*., 2008). Rural poverty in parts of Asia could be exacerbated (Skoufias et al., 2011) due to negative climate change impacts on the rice crop and increases in food prices and the cost of living (Hertel et al., 2010; Rosegrant, 2011). The poverty impacts of climate change would be heterogeneous among countries and social groups (see Table 24-6). In a low crop productivity scenario, food exporting countries, such as Indonesia, the Philippines and Thailand, would benefit from climate change related global food price rises and be able to reduce poverty, while countries such as Bangladesh would experience a net increase in poverty of 15% by 2030 (Hertel et al., 2010). Regression analyses conducted by Skoufias *et al.* (2011) indicate significant negative impacts of a shortfall in rainfall on the welfare of rice farmers in Indonesia, compared to a delay in the onset of rainfall. These impacts may lead to global mass migration and related conflicts (Laczko and Aghazarm, 2009; Barnett and Webber, 2010; Warner, 2010; World Bank, 2010). Climate-driven changes in tundra and forest-tundra biomes can influence indigenous peoples of the North Asia due to their traditional livelihood: nomadic tundra pastoralism, fishing and hunting (Kumpula *et al.*, 2011).

24.4.6.4. Vulnerabilities to Key Drivers

Key vulnerabilities vary widely within the region. Climate change can exacerbate current socio-economic and political disparities and add to the vulnerability of Southeast Asia and Central Asia to security threats that may be transnational in nature (Jasparro and Taylor, 2008; Lioubimtseva and Henebry, 2009). Apart from detrimental impacts of extreme events, vulnerability of livelihoods in agrarian communities also arises from geographic settings, demographic trends, socio-economic factors, access to resources and markets, unsustainable water consumption, farming practices and lack of capacity to adapt (Mulligan *et al.*, 2011; Acosta-Michlik and Espaldon, 2008; Allison *et al.*, 2009; Knox *et al.*, 2011; Lioubimtseva and Henebry, 2009; Byg and Salick, 2009; Salick and Ross, 2009; Salick *et al.*, 2009; Xu *et al.*, 2009; Winters *et al.*, 2009; UN, 2009). Urban wage labourers were found to be more vulnerable to cost of living related poverty impacts of climate change than those who directly depend on agriculture for their livelihoods (Hertel *et al.*, 2010). In Southeast Asia, an important topic of focus is forests and fires; for example the vulnerability of agriculture, forestry and human settlements on peatland areas in Indonesia (Murdiyarso and Lebel, 2007). Human health is also a major area of focus for Asia (Munslow and O'Dempseya, 2010), where the magnitude and type of health effects from climate change will differ within Asia depending on differences in socio-economic and demographic factors, health systems, the natural and built environment, land use changes, and migration in relation to local resilience and adaptive capacity. The role of institutions is also critical, particularly in influencing vulnerabilities arising from social heterogeneity based on gender (Ahmed and Fajber, 2009), caste and ethnic differences (Jones and Boyd, 2011), and securing climate-sensitive livelihoods in rural areas (Agrawal and Perin, 2008).

24.4.6.5. Adaptation Options

Cross-sectorial collaborations will be needed for the development of sustainable adaptive measures with interactions between the health sector and disaster preparedness programs, water management, sanitation, urban planning, the food industry and the animal health sector. Disaster preparedness on a local community level could include a combination of indigenous coping strategies, early-warning systems, and adaptive measures (Paul and Routray, 2010). Heat warning systems have been shown to be successful in preventing deaths among risk groups, as in Shanghai (Tan *et al.*, 2007). Also proven successful is the implementation of new work practices to avoid heat stress among outdoor workers, as shown in studies from Japan and the UAE (Joubert *et al.*, 2011; Morioka *et al.*, 2006). As described in section 24.7, there are many win-win solutions for public health from the interaction of adaptation and mitigation measures that involve urban environments and air pollution. Early warning models have been developed for haze exposure from wildfires, in for example Thailand (Kim Oanh and Leelasakultum, 2011). Early warning models are also being tested in infectious disease prevention and vector control programs, as for malaria in Bhutan (Wangdi *et al.*, 2010) and Iran (Haghdoost *et al.*, 2008), or are being developed, as for dengue fever region-wide (Wilder-Smith *et al.,* 2012).

The available literature suggests a need for identifying and promoting technologies and policy options that will provide both mitigation potential and sustained income generation potential in a changed climate (Bhandari *et al.*, 2007; Rosenzweig and Tubiello, 2007; Paul *et al*., 2009a). Interesting examples seem to emerge on how some practices provide completely unexpected livelihood benefits which otherwise may not be captured in standard evaluation frameworks, as in the case of the introduction of traditional flood mitigation measures in China which could positively impact the local livelihoods, leading to reductions in both the physical and economic vulnerabilities of communities (Xu *et al*., 2009). A significant amount of literature has stressed the greater role of local communities in decision making (Alauddin and Quiggin, 2008) and in prioritization and adoption of adaptation options (Prabhakar *et al*., 2010; Prabhakar and Srinivasan, 2011). Defining adequate community property rights, including solving issues such as land tenure, reducing income disparity, exploring market-based and diversified off-farm livelihood options, moving from production-based approaches to productivity and efficiency decision-making based approaches, and promoting integrated decision-making approaches, have been suggested (Merrey *et al*., 2005; Brouwer *et al*., 2007; Paul *et al*., 2009; Niino, 2011; Stucki and Smith, 2011).

Climate resilient livelihoods can be fostered through the creation of a bundle of capitals (natural, physical, human, financial and social capital) and poverty eradication (see Table 24-8). In general, greater emphasis on agricultural growth has been suggested as an effective means of reducing rural poverty (Janvry and Sadoulet, 2010; Rosegrant, 2011). Bundled approaches are known to facilitate better adaptation than individual adaptation options (Acosta-Michlik and Espaldon, 2008; Fleischer *et al*., 2011). Community-based approaches, as against top-down interventions, have been suggested to identify adaptation options that address poverty and livelihoods, as these techniques help capture information at the grassroots (Aalst *et al*., 2008), and help integration of disaster risk reduction, development, and climate change adaptation (Heltberg *et al*., 2010), connect local communities and outsiders (Aalst *et al*., 2008), and address the location-specific nature of adaptation (Iwasaki *et al*., 2009; Rosegrant, 2011). Some groups can become more vulnerable to changes after being ‘locked into’ specialized livelihood patterns as shown in the case of fish farmers in India (Coulthard, 2008).

[INSERT TABLE 24-8 HERE
Table 24-8: Summary of adaptation options for securing livelihoods in Asia.]

24.4.7 Valuation of Impacts and Adaptation

Research on the valuation of climate change impacts and adaptation in Asia has been highly limited. However, recently there is growing research attention to the assessment of the aggregate costs of climate change impacts and adaptation. For instance, in Bangladesh, by 2050, the total adaptation cost is estimated at US$5.7 billion to offset the added inundation from climate change, including US$3.3 billion to protect infrastructure, such as roads, railways, river embankments, and drainage from inland monsoon floods, and US$2.4 billion for storm-surge protection (World Bank, 2011). There are a few studies focusing on dispersed sectors though without comprehensive economic valuation of the costs and benefits of adaptation. Examples of such studies include exploring low-cost adaptation strategies for reducing the net vulnerability of sorghum production systems in India (Srivastava *et al*., 2010); assessing vulnerability and adaptation of agriculture and food security, water resources and human health in Central Asia (Lioubimtseva and Henebry, 2009); socio-economic impacts of drought and flood in South Asia (Muhammed *et al*., 2007); investigation of vulnerability and adaptive capacity to climate variability and water stress in the Lakhwar watershed in Uttarakhand State, India (Kelkar *et al*., 2008); assessing socio-economic vulnerability and adaptation measures in West Coast of Peninsular Malaysia (Drainage and Irrigation Department, 2007); and simulating impacts on rice yields in a number of Asian countries (Matthews *et al*. 1997). In addition to changes in temperature and rainfall, changes in the frequency of extreme climatic events could be damaging and costly to agriculture (Aydinalp and Cresser, 2008; Muhammed *et al*., 2007; Su *et al*., 2009).

A study of the economics of climate change in Southeast Asia with a focus on Indonesia, the Philippines, Thailand, and Vietnam (ADB, 2009) reported that many of the impacts from climate change are not in traditional economic sectors such as agriculture, including fisheries and aquaculture, forestry and mining, with the result that their valuations are difficult with uncertainly and incomplete information. Furthermore, some of the economic and social valuations, such as loss of life or damage to ecosystems, can be contentious. Without further mitigation or adaptation (under the A2 scenario), the PAGE2002 integrated assessment model projects for the four countries to suffer a mean loss of 2.2% of gross domestic product (GDP) by 2100 on an annual basis, if only the market impact (mainly related to agriculture and coastal zones) is considered. This is well above the world's mean GDP loss of 0.6% each year by 2100 due to market impact alone. In addition, the mean cost for the four ASEAN countries by 2100 could reach 5.7% of the GDP if non-market impacts related to health and ecosystems are included and 6.7% of the GDP if catastrophic risks are also taken into account.

The PAGE2002 model also found that the cost of adaptation for agriculture and coastal zones (mainly the development of drought- and heat-resistant crops and the construction of sea walls) would be about $5 billion/year by 2020 on average, and that this investment would be paid back in the future. For instance, the annual benefit of avoided damage from climate change is expected to exceed the annual cost by 2060 and, by 2100, benefits could reach 1.9% of GDP, compared to the cost at 0.2% of GDP, with the results at mean and 5% probability level under the A2 scenario. This shows that the benefits from adaptation are projected to outweigh the costs of implementing adaptation measures in the long term. It was also stressed that there are currently great uncertainties associated with the economic aspects of climate change (ADB, 2009). Adaptation cannot entirely remove the projected damage of climate change, and thus must be complemented with global mitigation of CO_2 in order to avoid the greater impact of future climate change (Begum *et al.*, 2011; ADB, 2009; MNRE, 2010).

24.5. Adaptation and Managing Risks

24.5.1. Conservation of Natural Resources

Even without climate change, natural resources are already under severe pressure in most of East, Southeast, and South Asia, as well as in much of Central and West Asia, and parts of North Asia and the Tibetan Plateau. The extraordinarily high rates of deforestation and forest degradation in Southeast Asia have received most attention (Sodhi *et al.*, 2010; Miettinen *et al.*, 2011), but ecosystem degradation, with the resulting loss of natural goods and services, is also a major problem in other forest types and in non-forest ecosystems. These pressures result from rising populations and rapid economic development, exacerbated by poor governance and the low priority of natural resource conservation. The impacts of projected climate change are expected to intensify these pressures in most areas, but the relative importance of climate and non-climate stressors is difficult to predict in most cases. Coral reefs are an exception, with climate change and ocean acidification a clear threat to all reefs in the region and thus the millions of people who depend on them (Hoegh-Guldberg, 2011; Burke *et al.*, 2011; see also Chapter 30, this volume).

With natural resource conservation already under stress, the focus has been on actions that would be beneficial even without climate change, including minimizing non-climate pressures on natural resources and restoring connectivity to allow movements of genes and species between fragmented populations (Lindenmayer *et al.*, 2010). Authors have also suggested a need to identify and prioritize for protection areas that will be subject to the least damaging climate change ('climate refugia') and to identify additions to the protected area network that will allow for expected range shifts, for example by extending existing protected areas to higher altitudes or latitudes (Hannah, 2010; Hole *et al.*, 2011; Shoo *et al.*, 2011). Moving beyond this focus on wild species and ecosystems, ecosystem-based approaches to adaptation aim to use the resilience of natural systems to buffer human systems against climate change, with potential social, economic and cultural co-benefits for local communities (see Box CC-EA: Ecosystem-based approaches to adaptation – emerging opportunities).

24.5.2. Flood Risks and Coastal Inundation

Many coasts in Asia are exposed to extreme weather, as well as more gradual changes in climate and sea level, and are accordingly anticipated to face threats from floods and coastal inundation. Responding to a large number of climate change impact studies for each country over the past decade (e.g. Karim and Mimura, 2008; Pal and Al-Tabbaa, 2009; World Bank, 2010), various downscaled tools to support, formulate and implement climate change adaptation policy for local governments are under development. One of the major tools is vulnerability assessment and policy option identification with Geographical Information Systems (GIS). These tools have been developed for flood risk management so far, and most give consideration in varying degrees to climate change impacts, such as long-term rises in sea-level. These tools are expected to be of assistance in examining city-specific solutions in response to city-specific impacts characterized by distinct climatic, hydrological and socioeconomic features, and in building the adaptation capacity of stakeholders in the community as a result.

These tools and systems sometimes take community-based approaches. The background to these is as follows: vulnerability and exposure to climate change at the coast is exacerbated by population growth, socio-economic growth and urbanization, however assessments of vulnerabilities have uncertainties and limitations and do not necessarily provide suitable information for local stakeholders to take appropriate action at the local level. Therefore bottom-up approaches are potentially more effective in building adaptive capacity by involving local stakeholders (Van Aalst *et al*., 2008). As local stakeholders have different sets of understanding, conflict assessment is needed to plan and implement adaptation policy (e.g. Baba *et al*., 2012). Also, community-based approaches may have a limitation in that they place greater responsibility on the shoulders of local people without necessarily increasing their capacity proportionately (Allen, 2006). As the nature of adaptive capacity varies, depending on the formulation of social capital and institutional context in the local community, it is essential for the approaches to have an understanding of local community structures (Adger, 2003). If the approaches satisfy these conditions, flood risks and coastal inundation exacerbated by climate change would be perceived as issues for the current generation and adaptation policy would be better understood by local stakeholders.

24.5.3. Economic Growth and Equitable Development

Economic, social, and environmental equity is an enduring challenge in many parts of Asia. Generally, the level of wealth (typically GDP) has been used as a measure of human vulnerability of a country or region, but this approach has serious limitations (Mattoo and Subramanian, 2012; Dellink *et al*., 2009; Bosetti and Frankel, 2009). In many cases, social capital, an indicator of equity in income distribution within countries, is a more important factor in vulnerability and resilience than GDP per capita (Lioubimtseva and Henebry, 2009; Islam *et al*., 2006). Furthermore, political and institutional instabilities can undermine the influence of economic development (Lioubimtseva and Henebry, 2009). Poor and vulnerable countries are at greater risk from the impacts of climate extremes as their options for coping which such events are limited. This is particularly true for developing countries in Asia with a high level of natural resource dependency. Provision of adequate resources based on the burden sharing and the equity principle will serve to strengthen appropriate adaptation policies and measures in such countries (Su *et al*., 2009). Mainstreaming adaptation into government's sustainable development policy portrays a potential opportunity for good practice to build resilience and reduce vulnerability, depending on effective, equitable and legitimate actions to overcome barriers and limits to adaptation (Lioubimtseva and Henebry, 2009; Agrawala and van Aalst, 2005; Lim *et al*., 2005; ADB, 2005). It requires growth with economic stability, development with social equity and poverty eradication, and the continued functioning of ecosystems as life support systems to sustain development.

24.5.4. Mainstreaming and Institutional Barriers

The level of climate change adaptation mainstreaming is most advanced in the context of official development assistance, where donor agencies and international financial institutions have made significant steps towards taking climate change adaptation into account in their loan and grant making processes (Gigli and Agrawala, 2007; Klein *et al*., 2007b). In contrast, within developing countries, actual projects on the ground to mainstream adaptation to climate change remain limited and significant institutional and cognitive barriers remain (Yohe *et al*., 2007; Gigli and Agrawala, 2007). For example, in the Philippines, the factors that hinder climate change mainstreaming include: national priorities that are geared towards what are perceived to be more pressing concerns, such as employment generation and education, and a pervasive lack of awareness of the impacts of climate change on sustainable development (Lasco *et al*., 2009). However, there are massive investments in infrastructure projects designed to adapt to weather-related hazards. Local government units could play a crucial role, as shown by the experience of Albay province in the Philippines which pioneered climate action at the grassroots level (Lasco *et al*., 2012)

While some practical experiences of adaptation in Asia at the regional, national and local level are emerging, there can be barriers that impede or limit adaptation. These can include lack of financial resources for adaptation implementation, institutional barriers, biophysical limits to ecosystem adaptation and others (Moser and Ekstrom, 2010). Regional adaptation strategies are necessary to tackle issues such as food security. There are already some groups, such as the Association of South East Asian Nations (ASEAN), but there is a need for global and regional strategic partnerships in this regard (Singleton *et al*., 2010). The success of deployment, implementation and sustainability of adaptation options can be influenced by the political economy of the region. Issues with resource availability might not only result from climate change, but also from weak governance mechanisms and the breakdown of policy and regulatory structures, especially with common-pool resources (Moser and Ekstrom, 2010). Furthermore, the impact of climate change depends on the inherent vulnerability of the socio-ecological systems in a region as much as on the magnitude of the change (Evans, 2010). Recent studies linking climate-related resource scarcities and conflict call for enhanced regional cooperation (Gautam, 2012).

24.5.5. Role of Higher Education in Adaptation and Risk Management

To enhance the development of young professionals in the field of climate change adaptation, it is of utmost importance to include the topic in higher education, especially in formal education programs. Shaw *et al*. (2011) emphasized the need for higher education in adaptation and disaster risk reduction in the Asia-Pacific region through: environment disaster linkage, focus on hydro-meteorological disasters, and emphasizing synergy issues between adaptation and risk reduction. Similar needs have also been highlighted by Ryan *et al*. (2010), Nomura and Abe (2010), Chhokar (2010) and Niu *et al*. (2010). Higher education should be done through lectures and course work, field studies, internships, and establishing education-research linkages by exposing the students to field realities. In this regard, guiding principles could include: an inclusive curriculum, a theoretical focus, field orientation, multi-disciplinary courses and practical skill enhancement. Bi-lateral or multi-lateral practical research programs on adaptation and risk management by the graduate students and young faculty members would expose them to the real field problems.

24.6. Adaptation and Mitigation Interactions

Climate change mitigation benefits climate change adaptation in Asia by increasing the prospects that adaptation can address many unavoidable impacts, and adaptation benefits mitigation by somewhat moderating the impacts of particular GHG concentration levels due to reduced sensitivities or increased coping capacities. One of the most prominent examples is increasing the efficiency and affordability of air conditioning, which would extend space conditioning benefits to a larger share of populations with rising standards of living, while at the same time reducing carbon emissions associated with electricity generation. Other examples include the development of sustainable cities in Asia with less fossil fuel driven vehicles (mitigation) and with more trees and greenery (carbon storage as well as adaptation to the urban heat island effect), which would have a number of co-benefits including public health – a promising strategy for “triple win” interventions (Romero-Lankao *et al*., 2011). A further example is China’s leadership in promoting solar energy technologies, where reduced requirements for carbon-based electricity generation are combined with technological change, job creation, and skill development that enhance adaptive capacities.

Other possible synergies (and/or conflicts) tend to be more subtle. In general, integrated mitigation and adaptation responses tend to focus on either land-use changes, often involving ecosystem functions, or on technology development and use. For instance, changes in land use, such as agroforestry, may provide both mitigation and adaptation benefits (Verchot *et al*., 2007), or otherwise depending on how they are implemented. Agroforestry practices will provide carbon storage and may at the same time decrease soil erosion, increase the resilience against floods, landslides and drought, increase soil organic matter, reduce the financial impact of crop failure, as well as have biodiversity benefits over other forms of agriculture as shown, for example, in Indonesia (Clough *et al*., 2011). Integrated approaches are often needed when developing mitigation-adaptation synergies, as seen in waste-to-compost projects in Bangladesh (Ayers and Huq, 2009). Linking adaptation to mitigation makes mitigation action more relevant for many low-income regions.

In addition to agroforestry, any ecological adaptation measures that increase plant biomass and/or soil carbon content, such as ecosystem protection and reforestation, will contribute to climate mitigation by carbon sequestration. However, exotic monocultures may fix more carbon than native species mixtures while supporting less biodiversity and contributing less to ecological services. Compromises that favor biodiversity-rich carbon storage that is resilient to future climate change may be necessary (Díaz *et al*., 2009). The potential for both adaptation and mitigation through forest restoration is greatest in the tropics (Sasaki *et al*., 2011). At higher latitudes (>45ºN), reforestation can have a net warming influence by reducing surface albedo (Anderson-Teixeira *et al*., 2012). The expansion of biofuel crops on abandoned and marginal agricultural lands could potentially make a large contribution to the mitigation of global carbon emissions, but could also have large negative consequences for both carbon emissions and biodiversity if it results directly or indirectly in the conversion of carbon-rich natural ecosystems to cropland (Fargione *et al*., 2010; Qin *et al*., 2011). Mechanisms, such as REDD+, that put an economic price on land-use emissions could reduce the risks of these negative consequences from biofuel expansion (Thomson *et al*., 2010), but the incentive structures need to be worked out very carefully (Busch *et al*., 2012).

There has also been an emphasis on forests and their management for providing resilient livelihoods and reducing poverty (Persha *et al*., 2010; Larson, 2011; Noordwijk, 2010; Chhatre and Agrawal, 2009). Securing rights to resources was found to be essential for greater livelihood benefits to the poor indigenous and traditional people (Macchi et al., 2008). Because of this, the need for REDD+ schemes to respect and promote community forest tenure rights has been emphasized (Angelsen, 2009). It has also been suggested that indigenous people can provide a bridge between biodiversity protection and climate change adaptation (Salick, 2009), which appears to be missing in the current discourse on ecosystems based adaptation. However, there are arguments against REDD+ supporting poverty reduction due to its inability to promote productive use of forests, which may keep communities in perpetual poverty (Campbell, 2009).

On rivers and coasts, the use of hard defenses (e.g. sea-walls, channelization, bunds, dams) to protect agriculture and human settlements from flooding may have negative consequences for both natural ecosystems and carbon sequestration by preventing natural adjustments to changing conditions. Conversely, setting aside landward buffer zones along coasts and rivers would be positive for both (Erwin, 2009), although this will often be difficult in practice. The very high carbon sequestration potential of the organic-rich soils in mangroves (Donato *et al*., 2011) and peatswamp forests (Page *et al*., 2011) provides opportunities for combining adaptation with mitigation through restoration of degraded areas.

Several mitigation technologies and measures will have public health benefits, such as controlled composting, state-of-the-art incineration, expanded sanitation coverage, and waste water management (Bogner *et al*., 2008). There are potentially large benefits for both public health and other sectors from climate change mitigation policies that reduce exposure to outdoor and indoor air-pollution (Haines *et al*., 2009). Decarbonizing electricity production efforts in India and China are projected to decrease mortality due to reduced PM5 and PM2.5 particulate matters (Markandya *et al*., 2009). Mitigation policies to reduce fossil fuel vehicles will increase air quality and decrease the health burden, particularly in urban environments as projected in India (Woodcock *et al*., 2009). The use of more public transportation, as well as increased walking and cycling, and fewer private cars could also improve public health (Woodcock *et al*., 2007). Abandoning the use of biomass fuel or coal for in-door cooking and domestic heating would substantially increase indoor air quality and respiratory and cardiac health among, in particular, women and children in India and China (Wilkinson *et al*., 2009). In reverse, actions to reduce current environmental-public health issues may often as an additional bonus have beneficial mitigation effects, like traffic emissions reduction programs in China (Wu *et al*., 2011) and India (Reynolds and Kandlikar, 2008). At the same time, climate change adaptation technologies, such as improved stormwater and wastewater management, can reduce electricity requirements for water pumping and water treatment; and advances in information, communication, and control technologies can contribute to both adaptation and mitigation efforts. Among financial means, low-risk liquidity options such as microfinance programs and risk transfer products can help lift the rural poor from poverty and accumulate assets (Barret *et al*., 2007; Jarvis *et al*., 2011).

24.7. Intra-regional and Inter-regional Issues

24.7.1. Trans-boundary pollution

Many Asian countries and regions face long-distance and trans-boundary air pollution problems. In eastern China, Japan and the Republic of Korea, these include dust storms that originate in the arid and semi-arid regions upwind, with impacts on climate, human health and ecosystems (Huang *et al*., 2013). The susceptibility of the land surface to wind erosion is strongly influenced by vegetation cover, which is in turn sensitive to climate change and other human impacts. In the humid tropics of Southeast Asia, in contrast, the major trans-boundary pollution issue involves smoke aerosols from burning of biomass and peatlands [24.9.2], mostly during clearance for agriculture. Apart from the large impact on human health, these aerosols may be having a significant effect on rainfall in equatorial regions, leading to the possibility of climate-feedbacks, with fires reducing rainfall and promoting further fires (Tosca et al., 2012; WG1 AR5 SOD Ch. 7). Pollutants of industrial origin are also a huge problem in many parts of the region, with well-documented impacts on human health [24.4.6] and the climate [WG1 AR5 SOD Ch. 7 and 8].

24.7.2. Trade and Economy

A well-functioning international trading system can help support adaptation to the challenges of climate change. Hence welfare gains from reforms to trade policies may be greater than normally measured if they also reduce GHG emissions globally (Huang *et al*., 2011). In recent years, there has been a growing interest in the environmental impacts of regional trade liberalization. A study by Gumilang *et al*. (2011) suggests that overall AFTA (ASEAN Free Trade Agreement) has had a greater impact on the Indonesian economy than IJEPA (Indonesia–Japan Economic Partnership Agreement), while the adoption of both agreements contributes to increasing CO_2 emissions by 0.47% compared to the business-as-usual case. This is mainly due to the high emission coefficient of the transportation sector. On the other hand, the agreements did have a positive impact on water pollution indicators.

China's high economic growth and flourishing domestic and international trade has resulted in increased consumption and pollution of water resources. For instance, Guan and Hubacek (2007) found that North China, as a water scarce region, effectively exports about 5% of its total available freshwater resources, while accepting large amounts of wastewater from other regions' consumption. By contrast, South China, a region with abundant water resources, is effectively importing water from other regions, while their imports are creating wastewater polluting other regions' ecosystems.

24.7.3. Migration and Population Displacement

There is an emerging body of literature suggesting growing nexus between migration and climate change (International Organization for Migration, 2008; Piguet *et al*., 2011). The global report of Internal Displacement Monitoring Center (2011) enlists climate related natural hazards such as floods and droughts as some of predominant causes for internal displacement. In 2010 alone, 38.8 million people were internally displaced 85% of them were due to hydrological hazards and 77% of displacements took place in Asia alone. Rapid-onset environmental changes such as floods are increasingly playing a role in migration in the case of Mekong Delta (Warner, 2010). Migration has also received attention in the literature as an adaptation option (Reuveny, 2007; Warner, 2010; ADB, 2012; The Government Office for Science, 2011). While some form of environmentally induced migration may be adaptive, other forms of environmental migration may indicate a failure of social-ecological systems to adapt (Warner, 2010), suggesting need for differentiating the root cause of migration and treating them through new forms of governance that connects the migrants with those who returned and remained.

Migration has become one of the strategies to sustain livelihoods in the wake of climate and environmental change (Barnett and Webber, 2010). The shift towards non-farm income activities, including migration, appears to be more prominent in countries and communities with least access to land (Winters *et al*., 2009) and in those communities with better access to education (Estudillo and Otsuka, 2010). Increasing migration has led to increasing migration-induced remittances contributing to Asian economies and decreased the poverty gap, but had negligible effect on the poverty rate (Vargas-Silva *et al.*, 2009).

Migration could have negative impacts on the migrants as observed in the case of Bangladesh where migrant workers had to live and work under poor conditions such as crowded shelters, poor sanitation, conflict and competition with local population, and exploitation (Penning-Rowsell *et al.*, 2011). Though forced migration can result from implementing some adaptation options such as construction of dams, the negative outcome from these migrations could be overcome by putting in place proper safeguards (The Government Office for Science, 2011). The most favorable approach is to deal with migration within a development framework and by incorporating into adaptation strategies (ADB, 2012; The Government Office for Science, 2011). Only such inclusive approach would make difference in whether climate induced migration would emerge as forced displacement or planned and facilitated adaptation strategy.

24.8. Research and Data Gaps

There are still regions within Asia that are not sufficiently represented in studies of observed climate change and its impacts, in particular Central and West Asia. Also, numerical data on trends in precipitation is hard to find compared to trends in temperature. Furthermore, research data on changes in extreme climate events does not cover most Asian regions. For freshwater resources studies, research priorities are as follows: (1) to increase the knowledge of future rainfall changes in regions by model ensembles to provide a better idea of future water supply, (2) to develop water management strategies across scales to adapt future changes in water demand and supply associated with climate change, (3) to elaborate more studies on successful water saving technologies and other adaptation options.

Scientific understanding of the impacts of climate change on ecosystems and biodiversity in Asia is currently limited by the poor quality and low accessibility of biodiversity information (GEO-5 Assessment Report, 2012). National biodiversity inventories are incomplete and very few sites have the accurate baseline information needed to identify changes brought about by climatic trends and other stressors. Quantitative information for sites in protected areas where non-climate impacts are minimized will be particularly valuable in the future. New and old data need to be digitized and made available on-line. Current warming projections suggest that large areas in the Asian tropical lowlands will experience climates in 2100 that have not existed anywhere on Earth for several million years (García-López and Allué, 2012). This novelty makes reliance on extrapolation from our current, limited, understanding of climatic controls on biological processes dangerous, and underlines the need for new research. Key priorities include the temperature dependence of carbon fixation by tropical trees and the thermal tolerance and acclimation capacity of both plants and animals (Corlett, 2011).

Boreal forest dynamics will be influenced by complex interactions between rising temperatures and CO_2 concentrations, permafrost thawing, forest fires, and insect outbreaks (Osawa *et al.*, 2010; Zhang *et al.*, 2011b). Understanding this complexity will require enhanced monitoring of biodiversity and especially of species ranges, improved modeling, and a greater knowledge of species biology (Anisimov *et al.*, 2008). Long-term monitoring of biome boundary shifts and vegetation change is also needed because of slow rate of these changes. In remote and inaccessible areas such monitoring has been provided since 1978 by broad-swath satellite remote sensing data, however lack of coincidence in estimates of vegetation vigor provided by remote sensing techniques and by vegetation models requires further research and inter-calibration of methods (Xu *et al.*, 2012).

There are still many gaps in our understanding of climate change impacts and vulnerabilities in the agricultural sector as well as appropriate adaptation options. The most studied crop is rice but there are still significant uncertainties in terms of accuracy of models, effect of CO_2 fertilization, and regional effects (Shuang-He *et al.*, 2011; Zhang *et al.*, 2010; Masutomi *et al.*, 2009). For other crops, there is even greater uncertainty in terms of magnitude and direction of impacts of rising temperatures, precipitation changes, and CO_2 fertilization.

There is a need to increase knowledge of heat and air pollution interactions and health effects in different risk groups, in both urban and rural environments. There are research gaps in climate change impacts on children's health in different socioeconomic and regional context to fill in. More trans-disciplinary research is needed on direct and indirect health effects from climate change impacts on water quality and quantity in different parts of Asia. Studies on social-economic and institutional dimension should also be given priority. For example, the impacts of climate change on women and their role in climate change adaptation needs to be investigated (Mula *et al.*, 2010). There is also a need to identify low cost adaptation options and a need for scaling up of the same, considering the majority of population lives below the poverty line in some of the least developed countries. Greater understanding of various existing policy processes in place-specific geographic context, their compatibilities and non-compatibilities, is also needed. For example, interventions to increase livelihood options through conservation initiatives that may restrict access to natural resources for the very people that rely upon them for their living might make them more vulnerable (Roman and McEvoy, 2010). Research on adaptation and mitigation interactions that promotes sustainable development should be increased, as well as research on possible economic gains from different adaptation-mitigation strategies and measures.

More focused research will support the tackling of climate change impacts, vulnerability and adaptation in urban settlements, especially cities with populations under 500,000, which share about half the region's urban population. Since urban areas account for over 80% of Asia's GDP, research priorities could include detailed estimates of the impact of climate change on various sectors of the urban economy, including the tourism industry (UN-Habitat, 2011). Research on promoting adaptation polices at the municipal level should also be given consideration. It is assumed that the existing policies should be expanded into adaptation; however the implementation of adaptation measures is still in its infancy.

Climate change will not have uniform impact on the population within a country, but rather depends on location, socio-economic conditions and level of preparedness (Begum *et al.*, 2011). Negative impacts on agricultural productivity would have significant impacts on the aggregated household welfare, livelihoods and poverty in the region (Zhai and Zhuang, 2009) and this needs to be adequately studied. Low cost options are limited, despite the number of people living below the poverty line in some of the least developed countries such as Bangladesh (Iwasaki *et al.*, 2009; Rawlani and Sovacool, 2011). Greater understanding is required on linkages between local livelihoods, ecosystem functions, and land resources for creating a positive impact on local livelihoods and poverty reduction in areas with greater dependency on natural resources (Paul *et al.*, 2009). Keeping in view the interconnected nature of the problems across geographical, social and political scales, an emphasis on increased regional collaboration in scientific research and policy making was suggested for reducing climate change impacts on water, biodiversity and livelihoods in the Himalayan region (Xu *et al.*, 2009).

While mitigation efforts are essential, the literature suggests that work must begin on building understanding of the impacts of climate change and moving forward with the most cost-effective adaptation measures (Stage, 2010; Mathy and Guivarch, 2010; Cai *et al.*, 2008; ADB, 2007). Consequently, for devising mitigation policies, the key information needed are the most cost-effective mitigation measures within sector and across sectors (Mathy and Guivarch, 2010; Cai *et al.*, 2008; Nguyen, *et al.*, 2007). The costs and benefits of climate change adaptation cannot be analyzed using economic aspects only; other aspects such as climate science, behavioral science, legal and moral aspects also have crucial implications for the outcome of the analysis (Stage, 2010; Agrawala and Fankhauser, 2008; Lecocq and Shalizi, 2007; Begum *et al.*, 2006; Metroeconomica, 2004).

24.9. Case Studies

24.9.1. Transboundary Adaptation Planning and Management – Lower Mekong River Basin

The *Lower Mekong River Basin (LMB)* covers an area of approximately 606,000 sq km across the countries of Thailand, Laos, Cambodia and Vietnam (Hinkel and Menniken, 2007). More than 60 million people in the densely populated LMB are heavily reliant on natural resources, in particular agriculture and fisheries for their well-being (MRC, 2009; UNEP, 2010). As two of the five top rice exporting countries globally, Thailand and Vietnam produced 51% of the world's rice exports in 2008. The majority of rice production in these countries is located in the LMB (Mainuddin *et al.*, 2011a). About two-thirds of the Mekong Basin's population is involved in fishing to sustain their livelihoods; fishing is particularly important for rural households (Hortle, 2009; Mainuddin et al., 2011b).

Although there is no precise data on the economic value of the LMB fisheries, the total value of inland fisheries in the entire Mekong River Basin (lower and upper) is US$3.9 – 7.0 bn per year, with the export of fish from the four LMB countries reaching about US$5.6 billion in 2008 (FAO, 2008; Mainuddin *et al*., 2011b; MRC, 2010a).

[INSERT FIGURE 24-3 HERE
Figure 24-3: Map of Lower Mekong Basin from Mekong River Commission Technical Paper No. 24, 2009 (MRC, 2009).]

Across the LMB countries observations of climate change over the past 30-50 years include (MRC, 2010b): an increase in temperature (for all riparian countries), rainfall increases in the wet season and decreases in the dry season (e.g. Thailand and Vietnam), intensified flood and drought events (e.g. Laos), and sea level rise (Vietnam's Mekong Delta). Agricultural output has been noticeably impacted by climate-related events. For example in Cambodia from 1996 to 2001, 70% of rice production loss occurred due to flooding and 20% due to droughts (MRC, 2009). In Laos, the areas of rain-fed rice fields destroyed by flooding were 55,172 ha per year on average between 1995 and 2005, accounting for 7% of the country's total cropland (MRC, 2009).Vietnam and Cambodia have been ranked as the countries most vulnerable to the impacts of climate change on their fisheries (Halls, 2009; Allison et al, 2009).

National level climate change adaptation plans have been formulated in all four riparian countries, but a commonly shared scientific forecast on possible future climate impacts as well as an integrated and coordinated adaptation program across the LMB does not exist to date. A range of individual studies that assess future LMB climate differ in the use of underlying climate models and emission scenarios. The existing studies however broadly share a set of expected *future climate changes* in the Mekong Basin (MRC, 2009): increases in temperature, wet season rainfall, and flooding frequency and duration along the Mekong River; decreases in dry season rainfall; sea level rise and salinity intrusion in the Mekong delta.

While significant uncertainties about both the magnitude and location-specific impacts of climate change in the LMB remain, it is expected that *vulnerabilities* will be exacerbated in three areas:

1) Changes in the spatial distribution of agricultural output rates and an overall reduction in food security (MRC, 2009; MRC, 2010b)
2) Loss of fertile land and population displacement in the Mekong river delta (MRC, 2009; MRC, 2010b)
3) Reduced fish survival, growth and reproductive success (UNEP, 2010)

A series of hydropower dams along the Mekong River and tributaries will change the hydrology in the LMB. Climate change, together with impacts from infrastructure development and land-use changes, will exacerbate these changes, likely resulting in disruption to fisheries, with a potential loss in both species diversity and production (Grumbine *et al*., 2012; Ziv *et al*., 2012; Wyatt and Baird, 2007).

To address the climate change related vulnerabilities, adaptation needs primarily arise in areas of improving water management, farming and fishing practices, as well as coastal protection (Johnson et al., 2010; Hoanh et al., 2003; Neo, 2012a). Transboundary initiatives to address climate change are driven by multiple actors, including the Mekong River Commission (MRC), the United Nations Development Program (UNDP) and the Asia Development Bank's Greater Mekong Sub-region programme (ADB GMS) among others (MRC, 2009; Lian and Bhullar, 2011). Despite these initiatives, strong inter-governmental policy development and planning coordination between ministries and different levels of government are largely absent, which has adversely affected the development and implementation of appropriate large scale adaptation strategies (Lian and Bhullar, 2011).

Key challenges and barriers for effective future transboundary adaptation planning and management include*:*

- Lack of a commonly shared scientific forecast on possible future climate impacts across LMB countries as the basis for transboundary adaptation planning (MRC, 2009)
- Sub-optimal coordination among adaptation stakeholders and sharing of best practices across countries (MRC, 2009)
- Insufficient mainstreaming of climate change adaptation into the broader policy frameworks of the national governments in all the four LMB countries (MRC, 2009; Lian and Bhullar, 2011)

- Insufficient integration of transboundary policy recommendations into national climate change plans and policies (Kranz *et al.*, 2010)

A stock-take study on the state-of-adaptation practice in the LMB was concluded recently (Ding, 2012; Neo, 2012b; Schaffer and Ding, 2012), showing that only 11% (= 45) projects out of a total of 417 climate change related projects were truly adaptation efforts. Of these 45 projects around 60% are targeting agriculture sectors and rural communities. The stock-take exercise found that no programmatic adaptation approaches were in place, but adaptation practice rather occurred on a project-by-project basis, with single country projects accounting for 89% of all adaptation projects in the LMB. The portfolios of these 45 adaptation projects are characterized by a broad range of actors that do not operate under a coordinated framework. Projects are rather reactive in nature, being developed in response to extreme local weather events or observed water shortages and lack elements of forward-looking strategic and anticipatory planning of expected future climate changes. The private sector is not involved in any adaptation project. Overall adaptation funding and capacity levels to scale up adaptation are limited.

The above study also developed a framework to identify ‘successful’ climate change adaptation projects in the LMB. Applying this framework to the identified 45 projects, 5 were characterized as successful and documented via case studies (Panyakul, 2012; Khim, 2012; Roth and Grunbuhel, 2012; Mondal, 2012; Brown, 2012). These case studies address issues of building coping capacity for farmers (Panyakul, 2012) or building multi-scale adaptation capacity (Roth and Grunbuhel, 2012) among others.

Common features of these ‘successful’ projects are:

- Local stakeholder knowledge together with analytical baseline assessments form the basis of robust initial gap assessments and input to the adaptation project planning.
- Multiple local stakeholders, especially local communities, are actively engaged throughout the course of the project.
- The participatory process in each stage of the project develops ownership at the local level and facilitates adoption of good adaptation practices.

Recognizing the state of adaptation practice, funding and capacity development challenges, similarities of climate risk across the LMB countries, diversity of funding and implementing actors and national sovereignty needs, Schaffer and Ding (2012) propose a multi-stakeholder Regional Climate Change Adaptation Action Network approach to enhance the effectiveness and efficiency of future climate change action. This proposed approach follows the theory and successful examples of the Global Action Networks (GANs) (Waddell, 2005; Waddell and Khagram, 2007; WCD, 2000; GAVI, 2011) with the intent of scaling up and improving mainstreaming of adaptation in the LMB.

24.9.2. Tropical Peatlands in Southeast Asia

Tropical peatlands develop only in flat lowland regions with year-round rainfall and are most extensive in Southeast Asia, particularly on the islands of Sumatra, Borneo, and New Guinea (Posa *et al.*, 2011). The largest areas are on coastal plains and river deltas, but peatlands can also develop inland on flat or gently convex areas between rivers. They eventually form dome-shaped structures less than 20 m deep that are above the local water table and fed only by rainwater. The modern peatlands of Southeast Asia are relatively young ecosystems, having started growth between the Late Glacial and Mid-Holocene, and peat accumulation appears to have ceased during the late Holocene in Central Kalimantan, possibly as a result of enhanced El Niño activity (Dommain *et al.*, 2011). In recent times these peatlands covered around 250,000 km^2 and contained more than 65 Gt of carbon, with two-thirds of this in Indonesia (Page *et al.*, 2011). Although traditionally viewed as species-poor, peat swamp forests provide an important habitat for much of the region’s fauna, including orangutans and a high diversity of specialized freshwater fish (Posa *et al.*, 2011).

Southeast Asian peatland ecosystems were largely intact in 1970 but have been massively impacted over the last 20 years, as a result of logging and conversion to oil palm and pulpwood (Acacia spp.) plantations (Murdiyarso *et al.*, 2010). Between 1990 and 2010, forest cover on the peatlands of Peninsular Malaysia, Sumatra and Borneo fell from

77% to 36%, to be replaced by industrial plantations of unknown sustainability and degraded areas covered in ferns, grasses and shrubs (Miettinen *et al*., 2011a). Draining the peat leads to shrinkage and microbial decomposition, and makes the peat itself highly flammable, so the degraded peatlands have become globally significant carbon sources, particular during ENSO-associated droughts (Miettinen *et al*., 2011b; Page *et al*., 2011). Pressures for peatland conversion continue despite these concerns. Tropical peatlands will be very vulnerable to any reduction in rainfall and/or increase in rainfall seasonality over the coming decades, since dry periods lead to lower water tables, enhanced peat decomposition, and greater susceptibility to fire (Page *et al*., 2011). On the other hand, the exceptionally high carbon content makes tropical peatlands a very attractive target for greenhouse gas mitigation projects involving the restoration of groundwater levels (Jaenicke, 2011).

24.9.3. Glaciers of Central Asia and Siberia

The Altai, Pamir, and Tien Shan glaciers represent significant part of the Asian alpine cryosphere supplying up to 40% of water to the Aral, Balkhash and IssikKul Lakes, and Ob and Tarim rivers (Aizen *et al*., 1995; 1998; Surazakov *et al*., 2007). All rivers, except the Ob R. discharge water to central Asian arid endorheic basins populated with over 150 million people from Turkmenistan, Afghanistan, Uzbekistan, Tajikistan, Kyrgyzstan, Kazakhstan, Mongolia and Xinjiang and other north-western provinces of China, and Russia. The rate of glacier area change varies (see Table 24-9). In the last 50 years (1960-2009), central Asian glaciers lost on average 10% of their area and 15% of their ice volume [WG1 AR5 Ch. 4 Section 4.3]. The estimation was based on two sources of remote sensing data over Altai-Sayan, Tien Shan and Pamir: Corona KH Mapping Program (1968-1975), Landsat ETM+ and ASTER images (1999-2003) plus ALOS PRISM 2009. The Altai-Sayan glaciers were evaluated since 1960 using aerial photos, the Tien Shan and Pamir glaciers were computed from 1973-1975 (Aizen, 2011). The accuracy of the changes in glacier area was derived from an independent study of the Akshiirak massif in Tien Shan (Aizen *et al*., 2007). The comparison revealed a 0.7% error in total area, this error was due to differences in manual glacier digitizing and the spatial resolution of the images used in the two studies. Error in total volume of glacier loss is 0.21% (Aizen *et al*., 2006). For the period from 1973 to 2003 glacier ice melt increases total river runoff in heavy glacierized basins by 8% compared to the period from 1942 to 1972 (Aizen *et al*., 2007; Aizen, 2011). The studies on regional (Aizen *et al*., 1997; 2010) and local (Finaev, 2004) climate change in Central Asia revealed a positive trend in annual/warm season air temperatures with more significant rate of air temperature growth at low elevations. According to Giese et al., (2007) warming was not steady, there were three main thrusts: 30th, 50th and 70th. Investigations on precipitation changes revealed negative trend over the SE Mongolia (Yatagai and Yasunari 1994), Northern China (Xu 2001) and inner /central Tien Shan (Aizen *et al*., 1997). Aizen *et al*. (2010), Finaev (2004) analyses declared that the average annual precipitation did not change significantly throughout central Asia, increasing only 0.9%. Areas with surplus precipitation were larger than areas with precipitation deficit, while the absolute values of positive differences were lower than the negative absolute values. Surplus precipitation occurred in winter and at low altitudes, in regions surrounding the Tien Shan mountains.

The glaciers of the Altai-Sayan mountains are located in the most northern periphery of the Central Asia mountain system at a south edge of the Arctic basin in Siberia (see Figure 24-4). Altai-Sayan glaciers lost on average 14% area from 1960s to 2009 (Surazakov *et al*., 2007; Shahgedanova *et al*., 2010; Aizen, 2011). The accelerated glacier melt and glacier area reduction in the Altai-Sayan was caused mainly by an increase of summer air temperatures by 1.03ºC for the last 50 years (Savelieva et al, 2000; Aizen et al., 2010). The elevation of glaciers in the Pamir mountains reaches 7,700 m a.s.l. (Muztagata-Kongur glacierized massifs). Pamir glaciers nourish the Amu Dariya River, the major Aral Sea water stream. During the last 50 years (1960-2009), the largest glacier area losses (up to 12-15%) have been observed in the western and south-western Pamir and the smallest in central and eastern Pamir (3- 5%) (Khromova *et al*., 2006; Aizen *et al*., 2010: 2011). The Fedchenko Glacier in central Pamir, which is the world's largest alpine glacier outside of the Polar regions (Kotlyakov, 1997; Aizen, 2011; Lambrecht *et al*., 2013) (72 km long, 714 km^2 area, and 900 m max ice thickness) retreated 755 m between 1958 and 2009, losing only 2 km^2. The Tien Shan glaciers are located in the largest mountain system in central Asia, stretching 2000 km from west to east. The Tien Shan glaciers are the major sources of water for Balkhash and IssikKul lakes, and the Sir Darya and Tarim rivers. Summer precipitation decreased by 10% and the Tien Shan glaciers lost 8.5% of their total area on average during the last 50 years. The largest glacier area lost is observed in the northern and western Tien Shan (14.3%) due to a decrease in annual precipitation (-20mm) at elevations above 3,000 m a.s.l. and increased air temperatures by 0.44°C. Smaller glacier recessions have been observed in the inner and central Tien Shan (10% and 5% respectively). In central Tien Shan glacier recession is minimal due to high-elevated accumulation areas (up to 7,000 m a.s.l.). Thus, the central Tien Shan and central Pamir glaciers have been revealed as more stable glaciers to climate changes in central Asia (Aizen, 2011; Bamber, 2012; Jacob *et al*., 2012; Lambrecht *et al*., 2013). The eastern Tien Shan lost 12% of the total glacier area. On average, air temperatures increased by 0.8°C and precipitation decrease by 7% at the equilibrium line altitude (ELA) between the 1960s and 2009 in Tien Shan (Aizen, 2011).

[INSERT TABLE 24-9 HERE
Table 24-9: Recent publications on central Asia glaciers changes.]

[INSERT FIGURE 24-4 HERE
Figure 24-4: The difference in losses of glacier area in Altai-Sayan, Pamir and Tien Shan. Remote sensing data analysis from 1960s (Corona) through 2009 (Landsat, ASTER and Alos Prism).]

Simulation models forecast that significant glacier degradation will begin when (ELA) has increased by 600 m compared to the end of the 20th century (Aizen *et al.,* 2007). Then, the area covered by central Asian glaciers may shrink by 40% and the glacier volume by 60% of the current state. The IPCC WGI TAR in five AOGCMs under a range of forcing scenarios for 2100 compared to 1961 to 1990 predict, on average, an increase in regional air temperature of 2ºC to 8ºC (about 4ºC) and an increase in magnitude of precipitation of 0.8-1.2 (about 1.1 times) (Giorgi *et al*., 2001). If the air temperature increases to the greatest predicted value, i.e. by 8ºC, and precipitation increases to its maximum predicted value, i.e. by 1.24 times the current rate, then the model predicts a 970 m increase in ELA and the number of Tien Shan glaciers, glacier covered areas, and glacier volume are predicted to shrink correspondingly by 94%, 69%, and 75% of the current state. However, under the threshold predicted conditions, if air temperature increases by 8ºC and precipitation decreases to the minimum predicted value, i.e. by 0.84 times the current rate, then current glaciations will disappear. If air temperature increases to the minimum predicted value, i.e. by 2ºC, and if precipitation increases to the maximum predicted value 1.24 times the current value, then the simulation model predicts almost no changes in the number of glaciers, glacier covered area (GCA), and glacier volume, while glacier runoff will increase by 1.25 times of the current value (Aizen *et al.,* 2007).

Further changes in glacier water resources availability will bring the CA closer to a tipping point of an irreversible ecological and socio-economical collapse, significantly contribute to progressive droughts and land degradation. Inflowing water discharges only through seepage or evaporation without glacier/snow transition, eventually develop saline water, many lakes will contract and the ecosystems will disrupt. In basins with small glacierized areas, the disappearance of small glaciers has already led to a decline in river discharge, strongly affecting downstream agriculture and settlements of the densely populated arid region [24.4.1].

The Altai and inner Tien Shan glaciers did not exist in the Bølling-Allerød (BP) and regenerated during the Young Dryas episode. Central Asian glaciers survived the warmest periods during the last 12,500 years, i.e., Holocene Thermal Maximum (circa 7,600BP), Medieval Climate Optimum, when mean air temperature was about 4.2ºC higher than modern, i.e. the annual average temperature in the last three decades. Since that, the mean air temperature should be at least 5ºC higher than modern (Aizen *et al*., 2013) to complete modern glacier disappearance (Aizen *et al.,* 2010).

24.9.4. Is the Aral Sea Dying?

The Aral Sea (see Figure 24-5) was a very large lake in Central Asia that was the fourth largest in area in the world before the 1960s (Letolle, 2008; Kostianoy and Kosarev, 2010). It is located in the Karakum and Kyzylkum deserts. Navigation and the fisheries (yearly catches of 44,000 tons) were developed there. The deltas of two major rivers of Central Asia, the Amudarya and the Syrdarya, that bring waters to the Aral Sea, were known for their fisheries, biodiversity, reed production, and muskrat rearing. The local population used to work in water infrastructure related spheres (Nihoul *et al.,* 2002; Zonn *et al.,* 2009).

[INSERT FIGURE 24-5 HERE
Figure 24-5: The satellite view of the Aral Sea acquired on 7 September 2012 from MODIS-Aqua. Image courtesy by A.G. Kostianoy (P.P. Shirshov Institute of Oceanology, Moscow, Russia) and D.M. Solovyov (Marine Hydrophysical Institute, Sevastopol, the Ukraine), based on the LAADS Web, NASA-Goddard Space Flight Center data (http://ladsweb.nascom.nasa.gov/). The red line indicates the Aral Sea coastline back in 1960. The yellow line indicates the border between Kazakhstan and Uzbekistan.]

Since 1960, the water resources of the Amudarya and Syrdarya rivers have been excessively used in order to increase irrigation of agricultural lands as well as to create artificial water reservoirs, which later proved to be irrational (Glantz, 1999; Kostianoy and Kosarev, 2010). Hence the water balance of the Aral Sea was disrupted, and irreversible changes in the regime of the sea occurred which later led to one of the “largest ecological disasters of the twentieth century” (Letolle and Mainguet, 1993; Micklin and Williams, 1996; Glantz, 1999). For the last fifty years a progressive desiccation of the Aral Sea and deterioration of its environment has been observed. During those years the sea surface shrunk from 66,100 km^2 (1961) to 10,400 km^2 (2008); the sea volume decreased to 110 km^3 from 1,066 km^3 (1961); the sea level fell by 24 m (in 1961 the maximum depth was 69 m); and its salinity (mineralization) increased from 10 to 116 p.p.t. in the western part and to 210 p.p.t. in the eastern part of the Large Aral Sea (Kostianoy and Wiseman, 2004; Zavialov, 2005; Kostianoy and Kosarev, 2010).

The ongoing Aral Sea desiccation and salinization have resulted in critical changes in its shape, physical and chemical state, and biodiversity. Related economic activities lost their importance. The consequences of the sea degradation represent a big threat to the quickly growing population in the Priaralie (from 14 m people in 1960 to 45 m in 2006) due to such factors as water quality loss, lack of fresh water, dust and salt storms, salinization of soils, various diseases, and regional climate change (Kostianoy and Kosarev, 2010).

Irrational use of waters of Amudarya and Syrdarya is not the only reason for the Aral Sea desiccation. Regional climate change (decrease in precipitation and increase in air temperature) also seems to play a significant role in this process. Assessments of the water amount precipitated over the Amudarya catchment area for the period between 1979 and 2001 showed a critical decrease from about 7.5 to 4.5 km^3 per month on average (Nezlin *et al.,* 2004). According to estimates of the IPCC AR4, the rise in the mean annual air temperature in the Aral region in 1960–2000 was 1^{0}C (IPCC, 2007; Lioubimtseva and Henebry, 2009). Thus, regional climate change significantly influenced the water balance of the Aral Sea in the past 30 years, leading to its “supplementary” desiccation in addition to irrational water use.

By 2012, the main progress in saving the Aral Sea was achieved only in the Kazakh part, with the Kokaral dam construction between the eastern part of the Large Aral Sea and the Small Aral Sea in August 2005 (Kostianoy and Kosarev, 2010). Today, the Small Aral Sea is slowly reviving and small fishery production is growing, while the Large Aral Sea keeps on disappearing. Since 2010, the former eastern part of the Large Aral Sea has been a wetland which is periodically filled with snowmelt and rain water and partly desiccated in the dry seasons. The western part of the Large Aral Sea, being a relatively narrow and deep lake, may slowly die in the absence of an external water supply (Kostianoy and Kosarev, 2010; Micklin, 2010; Breckle *et al.,* 2012; Kostianoy, 2012).

Frequently Asked Questions

FAQ 24.1: What will be the projected impact of climate change on freshwater resources in Asia by the 2050s?
Asia is a huge and diverse region, so both climate change and the impact on freshwater resources will vary greatly across it. Adequate water resources are particularly important for Asia because of the heavy dependence of the agricultural sector on precipitation, river runoff and groundwater. There is low confidence in the future climate projections of precipitation on a regional scale and thus in predictions of climate change impacts on water resources availability. However, water scarcity is expected to be a big challenge in many Asian regions because of increasing water demand from population growth and higher standards of living. Shrinkage of glaciers in central Asia is expected to increase due to climate warming, which will influence downstream river runoff in these regions. Better water management strategies are needed to ease water scarcity. Water saving technologies and changing to more drought tolerant crops have been found to be successful adaptation options in the region.

FAQ 24.2: How will climate change affect biodiversity and ecosystems in Asia?
Rising temperatures are already leading to changes in the timing of life-history events, including leafing, flowering and leaf fall in plants, and migration and breeding in animals, and these changes are expected to continue. Changes in temperature and, less predictably, rainfall will also lead to changes in the distributions of plants and animals, most dramatically in Northern Asia, where boreal forest and shrubs will expand into tundra, and evergreen conifers will invade deciduous larch forest. On mountains, species will move upslope. In much of Asia, however, fragmentation of natural ecosystems will limit the ability of species to track changes in climate, increasing the risk of extinctions. Impacts on inland waters will interact with a wide range of other human impacts, including dam construction and pollution, but are expected to have an overall negative impact on the biota. Negative impacts on coastal and marine biodiversity are likely in the tropics, with coral reefs particularly vulnerable to both warming and ocean acidification, and also for ice-dependent species in the Arctic.

FAQ 24.3: How is climate change affecting permafrost in Asia?
Permafrost (permanently frozen ground) has degraded in recent decades in Siberia, Mongolia, China and Central Asia, and it is projected that permafrost degradation during the 21st century will spread from the southern and low-altitude margins, advancing northwards and upwards. In the Asian Arctic, changes in permafrost and in storm wave energy, as a result of sea-level rise and retreating sea ice, make coasts more vulnerable to erosion. It is projected that rates of coastal erosion in Asian Arctic will increase during the 21st century.

FAQ 24.4: How will climate change affect food production and food security in Asia?
Climate change impacts on crop production will be generally negative for most crops in Asia. For rice, most simulation models show that higher temperatures will lead to lower rice yields as a result of a shorter growing period. However, some studies indicate that the CO_2 fertilization effect could lead to rice yield increases despite climate change. This uncertainty on the overall effects of climate change and CO_2 fertilization is also generally true for other crops such as wheat, sorghum, barley, and maize among others. The impacts of climate change specifically changes in temperature and precipitation regimes on food production and food security will vary within regions and countries, increasing yields for some areas (e.g. cereal production in north and east Kazakhstan) and decreasing yields for others (e.g. wheat in the Indo-Gangetic Plain of South Asia). There are many potential adaptation strategies, such as crop breeding, changing crop varieties, adjusting planting time, water management, diversification of crops and a host of indigenous practices.

FAQ 24.5: How will climate change affect human health in different parts of Asia?
More frequent and intense heatwaves will increase mortality and morbidity in vulnerable groups in urban areas. The transmission of infectious disease will be affected due to changes in air and water temperatures (such as cholera epidemics in coastal Bangladesh, and schistosomiasis in inland lakes in China) and altered rain patterns and water flows (e.g., affecting diarrheal outbreaks in rural children). Changes in the geographical distribution of vector-borne diseases will be most noted close to their distribution limits. Outbreaks of the vaccine-preventable Japanese encephalitis in the Himalayan region and malaria in India and Nepal have been linked to rainfall.

FAQ 24.6: Who are the people most at risk in Asia from climate change?
People living in low lying coastal zones and flood plains are probably most at risk from climate extremes in Asia, with vulnerability increased by rising sea-levels. Such areas are home to 50% of Asia's urban population. Asia has more than 90% of the global population exposed to tropical cyclones. Settlements on unstable slopes or landslide prone areas face increased likelihood of rainfall induced landslides. Rural poverty in parts of Asia could be exacerbated due to negative climate change impacts on the rice crop and increase in food price and cost of living. Urban population growth will lead to urban land-use and land-cover changes and in turn will have impacts on climate.

FAQ 24.7: What are the challenges in research on climate impacts, vulnerabilities and adaptation in Asia?
Because of its size and diversity, gaps in data are a bigger challenge for Asia than in other parts of the world. For example, trends in precipitation are less available than data on trends in temperature, data on observed climate change and changes in extreme climate events does not cover most Asian regions. For freshwater resources, new models of future rainfall changes, developing of water managing strategies and study on water saving technologies

are needed. Biodiversity data and data on biome boundaries shift are incomplete, and long-term monitoring, especially in protected areas is needed to fill these gaps. Studies on agricultural sector and appropriate adaptation options, on social-economic and institutional dimension, on urban settlements and industry should also be given priority. A particular challenge is to assess how the comprehensive economic, social and cultural transformation processes happening in most parts of Asia will influence future dynamics in vulnerability patterns and adaptive capacity of different countries, economic sectors and social groups.

Cross-Chapter Box

Box CC-TC. Case Study Building Long Term Resilience from Tropical Cyclone Disasters

[Yoshiki Saito (Japan), Kathleen McInnes (Australia)]

Tropical cyclones (also referred to as hurricanes and typhoons in some regions) cause powerful winds, torrential rains, high waves and storm surge, all of which can have major impacts on society and ecosystems. For example, Bangladesh and India account for 86% of mortality from tropical cyclones (Murray *et al.*, 2012), which is mainly due to the rarest and most severe storm categories (i.e. Categories 3, 4, and 5).

About 90 tropical cyclones occur globally each year (Seneviratne et al, 2012) although interannual variability is large. Changes in observing techniques particularly after the introduction of satellites in the late 1970s, confounds the assessment of trends in tropical cyclone frequencies and intensities. Therefore, SREX concluded that there is *low confidence* that any observed long-term (i.e. 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capability (Seneviratne, *et al.,* 2012; Chapter 2). There is also *low confidence* in the detection and attribution of century scale trends in tropical cyclones. Future changes to tropical cyclones arising from climate change are *likely* to vary by region. This is because there is *medium confidence* that for certain regions, shorter-term forcing by natural and anthropogenic aerosols has had a measurable effect on tropical cyclones. Tropical cyclone frequency is *likely* to decrease or remain unchanged over the 21st century, while intensity (i.e. maximum wind speed and rainfall rates) is *likely* to increase. Regionally specific projections have *lower confidencelower confidence* (see WG1 Box 14.2).

Longer term impacts from tropical cyclones includes salinisation of coastal soils and water supplies and subsequent food and water security issues from the associated storm surge and waves (Terry and Chui, 2012). However, preparation for extreme tropical cyclone events through improved governance and development to reduce their impacts provides an avenue for building resilience to longer term changes associated with climate change.

Densely populated Asian deltas are particularly vulnerable to tropical cyclones due to their large population density in expanding urban areas (Nicholls *et al.*, 2007). Extreme cyclones in Asia since 1970 caused over 0.5 million fatalities (Murray *et al.*, 2012) e.g., cyclones Bhola in 1970, Gorky in 1991, Thelma in 1998, Gujarat in 1998, Orissa in 1999, Sidr in 2007, and Nargis in 2008. Tropical cyclone Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities. Several-meter high storm surges widely flooded densely populated coastal areas of the Irrawaddy Delta and surrounding areas (Revenga *et al.*, 2003; Brakenridge *et al.*, 2012). The flooded areas were captured by a NASA MODIS image on 5 May 2008 (Figure TC-1).

[INSERT FIGURE TC-1 HERE
Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al.*, 2012).]

Murray *et al.* (2012) compared the response to cyclone Sidr in Bangladesh in 2007 and Nargs in Myanmar in 2008 and demonstrated how disaster risk reduction methods could be successfully applied to climate change adaptation (Murray et al, 2012). Sidr, despite being of similar strength to Nargis, caused far fewer fatalities (3,400 compared to over 138000) and this was attributed to advancement in preparedness and response in Bangladesh through experience in previous cyclones such as Bhola and Gorky. The responses included the construction of multi-storied cyclone shelters, improvement of forecasting and warning capacity, establishing a coastal volunteer network, and coastal reforestation of mangroves. Birkmann and Teichman, (2010) caution that while the combination of risk reduction and climate change adaptation strategies may be desirable, different spatial and temporal scales, norm systems, and knowledge types and sources between the two goals can confound their effective combination.

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Table 24-1: The 51 countries/regions in the six sub-regions of Asia.

Sub-region	Countries/Regions	
Central Asia (5)	• Kazakhstan • Kyrgyzstan • Tajikistan	• Turkmenistan • Uzbekistan
East Asia (7)	• China, Hong Kong Special Administrative Region (Hong Kong) • China, Macao Special Administrative Region • Japan	• North Korea • People's Republic of China (China) • South Korea • Taiwan Province of China (Taiwan)
North Asia (2)	• Mongolia	• Russia (East of Urals)
South Asia (8)	• Afghanistan • Bangladesh • Bhutan • India	• Maldives • Nepal • Pakistan • Sri Lanka
Southeast Asia (12)	• Brunei • Indonesia • Lao People's Democratic • Malaysia • Myanmar • Papua New Guinea	• The Philippines • Republic Cambodia • Singapore • Thailand • Timor-Leste • Vietnam
West Asia (17)	• Armenia • Azerbaijan • Bahrain • Georgia • Iran • Iraq • Israel • Jordan	• Kuwait • Lebanon • Occupied Palestinian Territory • Oman • Qatar • Saudi Arabia • Syria • United Arab Emirates • Yemen

Table 24-2: Summary of key observed past and present annual mean temperature trends in Asian countries/regions.

Sub-region	**Countries/Regions**	**Unit**	**Change (Period)**	**Reference**
Central Asia	Kazakhstan	°C/10y	+0.31 (1936-2005)	Kryukova *et al.*, 2009
	Kyrgyzstan	°C	+1.6 (1901-2000)	Iliasov *et al.*, 2003
	Tajikistan	°C/10y	+0.1 to +0.2 (1940-2005)	Karimov *et al.*, 2008
East Asia	Hong Kong	°C/10y	+0.12 (1885-2008), +0.16 (1947-2008), +0.27 (1979-2008)	Ginn *et al.*, 2009
	Japan	°C/100y	+1.15 (1898-2010)	JMA, 2011
	China	°C/10y	0.09±0.017 (1900-2006), 0.26±0.032 (1954-2006), 0.45±0.13 (1979-2006)	Li *et al.*, 2010
		°C/10y	+0.03 to +0.120 (1906-2005), +0.03 to +0.120 (1908-2007)	Ren *et al.*, 2012
	South Korea	°C	+1.87 (1908-2008), +1.37 (1954-2008), +1.44 (1969-2008)	Kim *et al.*, 2010
	Taiwan	°C/10y	+0.14 (1911-2009), +0.19 (1959-2009), +0.29 (1979-2009)	Hsu *et al.*, 2011
North Asia	Mongolia	°C	+2.14 (1940-2005)	Dagvadorj *et al.*, 2009
	Russia	°C	+1.29 (1907-2006), +1.33 (1976-2006)	Anisimov *et al.*, 2008
South Asia	Afghanistan	°C	+0.6 (1960-2008)	Savage *et al.*, 2009
		°C/10y	+0.13 (1960-2008)	
	Bangladesh	°C/10y	+0.097 (1958-2007)	Shahid, 2010
	India	°C	+0.56 (1901-2009)	Attri and Tyagi, 2010
		°C/100y	+0.68 (1880-2000)	Lal, 2003
		°C/y	+0.0056 (1948-2008)	Ganguly, 2011
	Nepal	°C/y	+0.06 (1977-1994)	Shrestha *et al.*, 1999
	Pakistan	°C	+0.57 (1901-2000), +0.47±0.21 (1960-2007)	Chaudhry *et al.*, 2009
		°C/10y	+0.099 (1960-2007)	
	Sri Lanka	°C/y	+0.005 to +0.035 (1961-2000)	Iqbal, 2010
		°C/10y	+0.3 to +0.93 (1869-2007), +0.75 to +0.94 (1910-2007)	de Costa, 2008
Southeast Asia	The Philippines	°C	+0.648 (1951-2010)	PAGASA, 2011
		°C/y	+0.0108 (1951-2010)	
West Asia	Armenia	°C	+0.85 (1935-2007)	Gabrielyan *et al.*, 2010
Tibetan Plateau		°C(°C/10y)	+1.8 (0.36/10y) (1961-2007)	Wang *et al.*, 2008
		°C/10y	+0.447 (1962-2001)	Xu *et al.*, 2008

Table 24-3: Summary of key observed past and present annual mean precipitation trends in Asian countries/regions.

Sub-region	**Countries/Regions**	**Unit**	**Change (Period)**	**Reference**
Central Asia	Kazakhstan	No definite national trend. (1936-2005)		Kryukova *et al.*, 2009
	Kyrgyzstan	mm	+23 (+6%) (1901-2000)	Iliasov *et al.*, 2003
	Tajikistan *plain region	%	+8 (insignificant) (1940-2005)	Karimov *et al.*, 2008
	*mountainos region	%	-3 (insignificant) (1940-2005)	Karimov *et al.*, 2008
	Turkmenistan	mm/10y	+12 (1931-95)	MNPT, 2000
East Asia	Hong Kong	mm/10y	+25 (1885-2008)	Ginn *et al.*, 2009
	Japan	No clear trend		MEXT *et al.*, 2009
	South Korea	%	+5.6 (2001-2008)	Kim *et al.*, 2010
North Asia	Mongolia	mm/y	-0.1 to -2.0 (1940-2005)	Dagvadorj *et al.*, 2009
	Russia	mm/10y	+7.2 (1976-2006)	Anisimov *et al.*, 2008
South Asia	Afghanistan	mm/m	-0.5 (1960-2008)	Savage *et al.*, 2009
		%/10y	-2 (1960-2008)	
	Bangladesh	mm/y	+5.53 (1958-2007)	Shahid, 2010
	India	No significant national trend (1901-2009)		Attri and Tyagi, 2010
	Pakistan	mm	+61 (1901-2007), -156 (1901-54), +35 (1955-2007)	Chaudhry *et al.*, 2009
	Sri Lanka	mm/y	-1.55 to -19.06 (1961-2000)	Iqbal, 2010
Southeast Asia	Indonesia *Brontas Catchment	mm/y	-1.23 to -24.25 (1955-2005)	Aldrian and Djamil, 2008
West Asia	Armenia	%	-6 (1935-2007)	Gabrielyan *et al.*, 2010
Tibetan Plateau		mm/y	+0.614	Xu *et al.*, 2008

Table 24-4: Summary of projected changes for a variety of climate parameters [WG1 AR5 SOD Ch. 14].

Sub-region	**T/P**	**Projected changes**
Central and North [AR5 WGI SOD 14.7.8]	T	Central: Similar warming magnitude in winter and summer. Northern: A stronger warming trend during winter.
	P	Central: Less certain Northern: *Very likely* increase. Central and Northern: *Likely* increase of extremes
East [AR5 WGI SOD 14.7.9]	T	*Very likely* increase by end of 21st C., more in summer than in winter. *Virtually certain* increase significantly over East Asia by end of 21st C., with larger magnitude over northern China and in winter (high confidence).
	P	Decrease mainly in winter, since there is very little precipitation in summer under present-day conditions. *Likely* increase of East Asian summer monsoon intensity throughout 21st C. and of summer precipitation over whole of East Asia (medium confidence) *Likely* increase over Yangtze River Valley, Korean peninsula and Japan during Meiyu-Changma-Baiu season in May-July. *Very likely* increase of extremes over most of southeastern China in all seasons, and over Japan in summer.
West and South [AR5 WGI SOD 14.7.10]	T	West and South: *Virtually certain* increase (high confidence)
	P	West and South: 'Wet gets wetter and dry becomes drier' but with large uncertainties West: *Likely* less precipitation in April to September half year (low to medium confidence) South: *Likely* more precipitation than at present (low to medium confidence)
Southeast [AR5 WGI SOD 14.7.11]	T	*Very likely* continuous warming through 21st C. (high confidence). *Likely* substantial sub-regional differences *Very likely* greater increase at night than during the day for all seasons *Very likely* continuous increase in hot days and warm nights, and decline in cooler weather.
	P	*Likely* averaged increase across the region with strong geographical variations (medium confidence)
T: Temperature, P: Precipitation		

Table 24-5: Summary of key observed past and present climate change impacts in Asia.

Sub-Region	Countries/Regions (Area)	***Parameters:*** Observed changes	Period	References
Central Asia	Kazakhstan (Steppe region in north)	***Normalized Difference Vegetation Index (NDVI):*** Decline (browning)	1982-2008	De Jong *et al.*, 2012
	Kazakhstan (Northern Tien Shan Mountains)	***Permafrost temperature at depths of 14-25 m:*** +0.3 to +0.6°C	1974-2004	Marchenko *et al.*, 2007; Zhao *et al.*, 2010
		Active layer thickness: +23%		
	Uzbekistan (Zerafshan River Basin)	***Water monthly discharge:*** Significant increases in spring and decreases in summer	1923-2006	Olsson *et al.*, 2010
	Kazakhstan, Uzbekistan, Kyrgyzstan (Main lakes)	***Surface area change:*** -49.62% (Aral Sea), -75.7% (Balk hash) , -2.61% (Ebinur), -8.37% (Issyk-Kul) +5.85% (Zaysan), -9.18% (Bosten)	1975-2007	Bai *et al.*, 2012
East Asia	Japan (Upper part of Kurobe Dam, Toyama)	***Runoff:*** Decreased by 40mm, slightly decreased and more in winter and spring, less in summer	1974-2004	Shinohara *et al.*, 2009
	Japan (Multiple sites)	***Spring leafing and flowering:*** Earlier by < 3 days per decade	Last 60 years	Ogawa-Onishi & Berry, 2013
		Changes in species distributions: Northwards by < 126 km per decade	Last 50-70 years	
	Japan (Seas around Japan)	***Changes in species distributions:*** Northwards expansion of fish, corals and algae.	Recent decades	Nagai *et al.*, 2011; Yamano *et al.*, 2011; Tian *et al.*, 2012.
	China (Shiyang River basin)	***Streamflow:*** Five of eight catchments showing significant decreasing trends	1950-2005	Ma *et al.*, 2008
	China (Dongjiang River)	***Runoff:*** Not significant change. Clear increased trend at two of three stations in low-flow period	1956-2000	Liu *et al.*, 2010a
	China (Tarim River Basin)	***Streamflow:*** Three of four river with increasing streamflow except Akesu River	1960-2005	Zhang *et al.*, 2010
		Mainstreams runoff: Decreased by 41.59% (1970s), 63.77% (1980s), 75.15% (1990s)	1957-2003	Hao *et al.*, 2008
		Runoff: In 1990s runoff from headwaters of Aksu and Yarkand River increased by 10.9%	1955-2000	Chen *et al.*, 2007b
	China (Baimashi Basin)	***Runoff:*** Decreased by 1.88% per year, decreasing from 1960s	1950-2000	Wang *et al.*, 2010
	China (Upper reaches of Tarim River Basin)	***Runoff:*** Aksu River showed a significant increasing trend with 10.9%. Three of four rivers showed an increase trend with one showed subtle reduction	1958-2004	Yaning *et al.*, 2009
	China (Laohahe Basin)	***Runoff:*** Runoff in 1980-2008 decreased by 36% compared with 1964-1979	1964-2008	Jiang *et al.*, 2011
	China (Hun-Tai River Basin)	***Streamflow:*** Downward trends	1961-2006	Zhang *et al.*, 2011
	China (Kaidu River Basin)	***Runoff:*** Increasing with rate of 8.4mm/decade; 1994-2009 increased 26.4% compared to 1960-1993	1960-2009	Chen *et al.*, 2012
	China (Haihe River Basin)	***Runoff:*** Significant downward trends	1957-2000	Wang *et al.*, 2012
	China (Pearl River, Yangtze River, Yellow River, Liao River, Songhua River)	***Runoff:*** Increased by 10% (Pearl River), had little change (Yangtze River), decreased by 80% (Yellow River), decreased by 54% (Liao River), decreased by 14% (Songhua River)	1951-2000	Xu, K. H. *et al.*, 2010
	China (Qinghai-Tibetan Plateau)	***Active layer thickness along Qinghai-Tibetan Highway:*** Mean rate of +7.5 cm/year	1995- 2007	Wu & Zhang, 2010
		Position of lower altitudinal limit of permafrost in north: Moved up by 25 m	Last 30 years	Cheng & Wu, 2007; Li *et al.*, 2008
		Position of lower altitudinal limit of permafrost in south: Moved up by 50-80 m	Last 20 years	
		Total area of glaciers of QTP and surrounding areas: Decreased by c. 9%, from 13363 ± 668 km^2 to 1213 ± 607 km^2	1970s-2000s	Yao *et al.*, 2012
	China (Whole country)	***Start of plant growth in spring:*** Earlier start by 2.9 days per decade	Last 30 years	Ma and Zhou, 2012
	China	***Rice yield*:** Positive correlation to temperature.	1981-2005	Zhang *et al.*, 2010
	Taiwan (Mountains)	***Plant distributions:*** Upper limits shifted upwards by 3.6 m per year	1906-2006	Jump *et al.*, 2012
North Asia	Mongolia (Kherlen River Basin)	***Underground water storage:*** No evidence for long-term storage change	1947-2006	Brutsaert, W. *et al.*, 2008
	Mongolia (Khentey Mountains)	***Growth of Siberian larch forest in forest-steppe ecotone:*** a. Tree-ring analysis shows a decreasing annual increment. b. Regeneration of larch decreased	1940s -2010	Dulamsuren *et al.*, 2010a; 2010b
	Mongolia (Hovsgol Mountain region)	***Mean annual ground temperature at 10 m depth:*** Increased on average by 0.02-0.03°C/year	Last 10-40 years	Sharkhuu *et al.*, 2008; Zhao *et al.*, 2010
	Mongolia (Hangai and Khentei Mountain regions)	***Mean annual ground temperature at 10 m depth:*** Increased on average by 0.01-0.02°C/year	Last 10-40 years	Sharkhuu *et al.*, 2008; Zhao *et al.*, 2010

	Russia, East of Urals (Siberia)	***Forest-tundra ecotone:*** a. Larch stands crown closure, and larch invasion into tundra at a rate of 3-10 m/year. b. Shrub expansion in arctic tundra as result of an increase in shrub growth.	1970-2000	Kharuk *et al.*, 2006; Myers-Smith *et al.*, 2011; Blok *et al.*, 2011
		Distribution of dark needle conifers (DNC), Siberian pine, spruce and fir: Invasion of DNC and birch into larch habitat	1980-2010	Kharuk *et al.*, 2010c, d; Osawa *et al.*, 2010; Lloyd *et al.*, 2011
		Permafrost temperature at zero annual amplitude: Warming of permafrost in most permafrost observatories in Asian Russia by 0.5-2°C.	1970s-1990s	Romanovsky *et al.*, 2008, with supplement; Romanovsky *et al.*, 2010
		Permafrost temperature at zero annual amplitude: No significant warming.	2000-2007	
		Permafrost temperature at zero annual amplitude: Warming of permafrost resumed at many locations predominantly near Arctic coasts.	2007-2008	
	Russia, East of Urals (Asian Arctic)	***Average erosion rate of coastline:*** 0.27-0.87 m/year	-	Lantuit *et al.*, 2012
	Russia, East of Urals (Ural Mountains)	***Area of glaciers:*** Decreased by 20-30% in total	1953-1981	Anisimov *et al.*, 2008
	Russia, East of Urals (Kodar Mountains)	***Area of glaciers:*** Exposed ice area (EIA) declined by c. 44%	ca. 1963-2010	Stokes *et al.*, 2013
		Area of glaciers: EIA declined by c. 40%, from 11.72 ± 0.72 km^2 to 7.01 ± 0.23 km^2	1995-2010	
	Russia, East of Urals (Suntar Khayata Range)	***Area of glaciers:*** Decreased by19.3%	Mid. 20th C.-2003	Ananicheva *et al.*, 2005, 2006
	Russia, East of Urals (Chersky Range)	***Area of glaciers:*** Decreased by 28 %	1970-2003	Anisimov *et al.*, 2008
	Russia, East of Urals (Kamchatka)	***Area of glaciers:*** Decreased for some glaciers, increased for others	Since Mid 19th C.	Anisimov *et al.*, 2008
South Asia	India (Upper Indus Basin)	***Water stress:*** No strong evidence for marked reduction in water resources	1961-2004	Archer *et al.*, 2010
	India (Headwater of Kosi River)	***Water resources:*** Reducion in groundwater recharge, 36% of springs have dried, heads of perennial streams have dried and water discharge in springs and streams have decreased considerably	1990-2010	Tiwari & Joshi, 2012
	India (Andaman Islands)	***Coral health:*** Mass bleaching	2010	Krishnan *et al.*, 2011
	Nepal (Himalayan region)	***Water resources:*** Significantly moving snowline		Karki *et al.* 2009;
	Nepal (Shorong, Khumbu, Langtang, Dhaulagiri, Kanchenjunga)	***River discharge:*** Decreasing trend in Karnali and Sapta Koshi; increasing trend in Narayani. No trend in southern rivers.	1970s-2000s	Shrestha & Aryal 2011
	Pakistan, India, Nepal, Bhutan (Himalayas)	***Start of plant growth in spring:*** Earlier start by 1.9 days per decade	1982-2006	Shrestha *et al.*, 2012
		Livelihoods: Leave farming due to repeated droughts	-	Kulkarni & Rao, 2008
Southeast Asia	Republic Cambodia	***Poverty:*** Loss of crops, income and fallows	-	Kulkarni & Rao, 2008
	Indonesia (Province of Papua)	***Area of mountain glaciers Puncak Jaya, Central Cordillera, New Guinea Island:*** Reduced from 19.3 km^2 to 7.3 km^2 (Mid 19th C.-1972), Reduced from 7.3 km^2 to 2.1 km^2 (1972-2002)	Mid 19th C. - 2002	Prentice & Glidden, 2010; Allison, 2011
	Malaysia (Mt Kinabalu, Sabah)	***Altitudinal distributions of moth species:*** Uphill shifts by average 83 m (upper) and 86 m (lower)	1965-2007	Chen *et al.*, 2011
	Indonesia, Malaysia, Singapore	***Coral health:*** Mass bleaching and subsequent mortality	2010	Guest *et al.*, 2012
West Asia	Jordan	***Wheat and barley yield*:** In 1999, total production and average yield for wheat and barley were lowest among years due low rainfall which was 30% of average.	1996-2006	Al-Bakri *et al.*, 2010
	Azerbaijan, Georgia (Southern macroslope of Greater Caucasus Range)	***Area of glaciers:*** Decreased by 31.2% in total	1895-2000	Anisimov *et al.*, 2008
	Iran, Iraq, Kuwait, Qatar, Saudi Arabia, UAE	***Coral health:*** Mass bleaching and subsequent mortality	1996-2012	Coles & Riegl, 2013
Kazakhstan, Kyrgyzstan, Tajikistan, China, Mongolia, Russia (East of Urals), Afghanistan (Altai-Sayan, Pamir, and Tien Shan Mountains)		***Area of glaciers:*** Decreased on average by 10%, accuracy of area loss estimate: 0.7%	1960-2009	Aizen, 2011; Aizen *et al.*, 2006, 2007
		Ice volume of glaciers: Decreased on average by15%, accuracy of volume loss estimate: 0.21%		
East and South Asia		***Poverty:*** Disproportionately impacts by climate related hazards	-	Kim, 2011
East and Southeast Asia (Mekong region)		***Livelihoods:*** Increased migration due to environmental (e.g. rapid onset disasters), social and economic reasons	-	Warner, 2010; Black *et al.*, 2011

Table 24-6: Summary of key future climate change impacts in Asia.

Sub-Region	Countries/Regions (Area)	***Parameters***: Projected impacts	Scenario/GCM (RCM)/Period (Base year)	Reference
Central Asia	N. & E. Kazakhstan	***Crop yield (cereal):*** Benefit from longer growing season, warmer winters and slight increase in winter precipitation		Lioubimtseva & Henebry, 2009
	W. Turkmenistan & Uzbekistan	***Crop yield (cotton):*** Negative impacts by frequent droughts		
East Asia	Japan (Tohoku and Hokuriku)	***River discharge:*** 200% higher in Feb., 50-60% lower in May.	A1B/AGCM/2080-2099 (1980-99)	Sato, Y. *et al*., 2012
	Japan	***Rice transplanting date:*** Northward shift of isochrones of safe transplanting dates for rice seedlings.	A2/MRI-CGCM2 (RCM20) /2081-2100 (1971–2000)	Ohta & Kimura, 2007
	China (Tarim River Basin)	***Flow:*** Positive change 1.3-12.8% in BYBLK and 17.7-29.7% in DSK	A2, A1B, B1/18GCMs/2046-65 (1979-98)	Liu *et al*., 2011
	China (Poyang Lake)	***Annual catchment inflow:*** Increased by 2.9% (A1B) and 6.5% (B1), decreased by 5.2% (A2).	A1B, B1, A2/ ECHAM5/ 2011-50 (1961-2000)	Ye *et al*., 2011
	China (Qinghai-Tibet Plateau)	***Permafrost area:*** Decrease by <19% (20-50 years since 1996), Decrease by 58% (2099)	+1°C in air temp. in 30 years since 1996/HADCM2/20-50 years since 1996, 2099 (1996)	Results of Li & Cheng (1999) after Cheng & Wu (2007)
	China (Tibetan Plateau)	***Alpine vegetation:*** Most replaced by forest and shrubland	A1B/Pattern-scaled output of multiple models/2070-2099 (1931-1960)	Wang *et al*., 2013
	China (Huang-Hai Plain in northeast China)	***Winter wheat yield:*** Increase by 0.2 Mg/ha (2015-45), Increase by 0.8 Mg/ha (2070-99)	A2, B2/HadCM3/2015-45,2070-99 (1961-90)	Thomson *et al*., 2006
	China (Huang-Huai-Hai (3H) Plain)	***Wheat-maize relative yield change (RYC):*** a. +2ºC & +5ºC in temp., +15 & -30% in prec., 500 & 700 ppmv CO_2: Decreased on average by -10.33%. b. a. with CO_2 fertilization: +4.46±14.83% (2ºC), -5.78±25.82% (5ºC). Base year: 1996-2004.		Liu *et al*., 2010
	South Korea (Han, Nakdong, Gum, Sumjin, Youngsan River Basin)	***Runoff:*** Four major river basins decrease 10% by 2030	A2/ ECO-G (MM5)/ 2001-30, 2016-45 (1961-2001)	Chang *et al*., 2007
	South Korea	***Paddy irrigation requirements:*** Decrease by 1-8%	A2, B2/HadCM3(RCMs)/ 2010-2039, 2040-2069, 2070-2099 (1961-90)	Chung *et al*., 2011
		Volumetric irrigation demand: Decrease by 4-10%		
	South Korea (Soyang, Chungju, Daecheong Basins)	***Annual mean streamflow:*** Reduced by 7.6%	$2\times CO_2$/YONU GCM (WGEN)/ 2031-50 (1961-80)	Kim *et al*., 2007
	China, Taiwan province (Upstream catchment of Shihmen reservoir)	***Runoff:*** Future runoff may be higher during wet season and lower during dry season.	A2, B2/CCSR, CGCM2, CSIRO, ECHAM4, GFDL, HADCM3/2010-39; 2040-69; 2070-99 (1973-2000)	Yu & Wang, 2009
	China (Taiwan province)	***Annual renewable water resource:*** Drop by 12.3%	A1B/JAM/MRI TL 959L60/2080-99 (1949-2000)	Tsai & Huang 2012; Li *et al*., 2010
		Water resource condition for Five levels: good (L1), good (L2), fair(L3), poor (L4), very poor (L5): No change in northern and eastern parts with L2; visibly deteriorate in southern part with L3 to L4; central part will be L4	A1B/ JAM/MRI TL 959L60/2080-99 (1979-98)	Tsai, et al., 2011
North Asia	Russia, East of Urals (Siberia)	***Tundra area:*** Decrease by 93% as result of boreal forest expansion	+1% GHG per year/HADCM3 (GGa1)/2090-2100 (1964)	Tchebakova *et al*., 2010
		Steppe area: Increase by 27%		
	Russia, East of Urals (Asian Russia)	***Tundra area:*** Decrease by 3% as result of boreal forest expansion	+1°C in annual mean global surface temp./ECHAM4/OPYC3, HadCM3a, IAP RAS CM/Late 2030s - early 2050s (1961-90)	Golubyatnikov & Denisenko, 2007
		Steppe area: Decrease by < 65%		
	Russia, East of Urals (Asian Arctic)	***Coast recession rate:*** Increase by 1.5- to 2.6-fold	+2°C in annual mean global surface temp. over 21st C., /2100 (c. 2000)	Pavlidis *et al*., 2007
	Russia, East of Urals (Arctic)	***Ice-dependent mammals***: Population declines in some species	Various/Various/21st C.	Kovacs *et al*., 2011
	Russia (East of Urals)	***Frequency of shortfalls:*** +3-4 years/decade in 2070s	A2, B2/ECHAM, HadCM3/2070s (1961-90)	Alcamo *et al*., 2007
South Asia	India(All)	***Forests:*** 34-39% of forests to change forest type	A2, B2/HadRM3/2085 (1931-60)	Chaturvedi *et al*., 2011
	India (Indo-Gangetic Plains,	***Sorghum winter grain yield:*** Reduced by up to 7% by 2020, up to 11% by	A2a/HadCM3/2020, 2050, 2080 (1970-95)	Srivastava *et al*., 2010

	Indore, Hyderabad, Dharwad)	2050 and up to 32% by 2080		
	Pakistan(Swat & Chitral districts)	***Wheat yield:*** -7% & -24% (Swat district), +14% & -23% (Chitral district).	1.5 & 3°C in temp./ (1976-2000)	Hussain & Mudasser, 2007
Southeast Asia	Indonesia (Java & Bali)	***Date of rice planting:*** Shift with marked increase in probability of a 30-day delay in monsoon onset in 2050	A2, B1/Ensamble/2050 (1979-2004)	Naylor *et al.*, 2007
West Asia	Iran (all)	***Deep aquifer recharge:*** Decreases by 50-100% in groundwater recharge in earstern	A1B; B1; A2/CGCM 3.1/2010-40, 2070-2100 (1980-2002)	Abbaspour *et al.*, 2009
	Jordan (Upper Jordan; Wadi Faynan)	***Stream flows, flood flow and numbers:*** Decrease by 12%	A2/(HadRM3)/ 2071-2100 (1961–1990)	Wade *et al.*, 2010
	Jordan (Yarmouk basin)	***Wheat and barley yield:*** a. Reduction of rainfall by 10-20%: - 4 to -8% (barley), -10 to -20% (wheat). b. Increase of rainfall by 10–20%: +3 to +5% (barley), +9 to +18% (wheat). c. Increase of air temp. by 1, 2, 3, 4°C: +14%, +28%, +38%, +46% (barley), +17%, +4%, +43%, +113% (wheat)	DSSAT/CSIROMK3, ECHAM5OM, HADGEM1/2050 (1960–2005)	Al-Bakri *et al.*, 2010
Eastern Mediterranean and Middle East region		***Internal water resource:*** Decreases from 464 to 419 and 412km^3	A1B /HadCM3 (PRECIS)/2040-69, 2070-99 (1961-90)	Chenoweth *et al.*, 2011
		Runoff: -9.5% & -10% (Tigris-Euphrates River), -22% & -30% (Jordan River)		
North Asia, East Asia, Central Asia	Asian Russia, China, Mongolia, Kazakhstan (Permafrost area in Asia)	***Permafrost degradation:*** Spread from southern and low-altitude margins, advancing northwards and upwards	Multiple scenarios/Multiple GCMs/21st C.	Multiple references, see section 24.4.2.3.
North, East Asia	Asian Russia, China (Siberia and Tibet)	***Permafrost distribution:*** Permafrost will remain only in Central and Eastern Siberia and in part of Tibet	A1B, A2/IAP RAS CM/Late 21st C.	Eliseev *et al.*, 2009
West, South, Southeast Asia (all countries with tropical coasts)		***Coral health:*** Large declines in structure and diversity	Several/Several/2050	Hoegh-Guldberg, 2011; Burke *et al.*, 2011
Asia		***Poverty:*** Negative impact on rice crop, increase in food price and cost of living, increased poverty, projections for 2030 by GTAP Model under three scenarios resulting low, medium and high productivity		Hertel *et al.*, 2010
Central, East, South, Southeast Asia (Tibet/Himalayas)		***Livelihoods:*** Loss of livelihoods to indigenous people from declining alpine biodiversity		Salick *et al.*, 2009; Xu *et al.*, 2009

Table 24-7: Summary of adaptation options for agriculture in Asia.

Crop	Country/ Regions	Recommended/ Potential Adaptation strategies	Benefits/ Co-Benefits	References
Wheat	General	Conservation agriculture (reductions in tillage, surface retention of adequate crop residues, and diversified, economically viable crop rotations)	Improve rural incomes and livelihoods by reducing production costs, managing agroecosystem productivity and diversity more sustainably, and minimizing unfavorable environmental impacts	Ortiz *et al.*, 2008
Wheat	Pakistan	Development of short duration and high yield varieties of wheat.	Can withstand climatic anomalies expected in future	Hussain & Mudasser 2007
Wheat	Indo- Gangetic Plains, India	Development of heat-tolerant wheat germplasm, as well as cultivars.	Better adapted to heat and conservation agriculture	Ortiz et al., 2008
Barley; wheat	Jordan	Soil water conservation. Selection of drought tolerant genotypes with shorter growing seasons.	Increase available water to crop	Al-Bakri *et al.*, 2010
Sorghum	India	Changing variety and sowing date	Reduce impacts on monsoon sorghum to about 10%, 2% and 3% in 2020 scenario. Reduced impacts on winter crop to 1–2% in 2020, 3–8% in 2050 and 4–9% in 2080.	Srivastava *et al.*, 2010
Rice	Sri Lanka	Traditional approaches for resolving water stress, such as increasing water use efficiency, water harvesting and/or reducing cropped areas. Earlier planting and shorter duration varieties to avoid impacts of less rainfall in January and February.		De Silva *et al.*, 2007.
Rice	China	Shifts in planting dates and automatic application of irrigation and fertilization. Selection for more temperature-tolerant cultivars and later-maturing cultivars to take advantage of longer growing seasons		Tao *et al.*, 2008
Corn	China	Using high-temperature sensitive varieties Early planting, fixing variety growing duration, and late planting	Using high-temperature sensitive varieties, maize yield could averagely increase by 1.0-6.0%, 9.9-15.2%, and 4.1-5.6%, by adopting adaptation options of early planting, fixing variety growing duration, and late planting, respectively	Tao & Zhang, 2010
General	India	Water harvesting		Kelkar *et al.*, 2008
General	South Asia	Increasing livestock production relative to crops Selection of crop varieties Livelihood diversification		Morton, 2007
General	Central Asia	Replacement of existing network of open irrigation canals by more efficient drip irrigation systems Development of early warning systems, such as drought forecast, pest and epidemic disease forecasts, and water quality monitoring systems.	Could significantly reduce evaporative water loss, while simultaneously improving crop productivity, reducing soil salinization, and decreasing risks of water contamination and transmission of vector-borne and waterborne diseases.	Lioubimtseva & Henebry, 2009
General	West Asia	Changing of cropping systems and patterns, switching from cereal-based systems to cereal–legumes and diversifying production systems into higher value and greater water use efficient options. Using supplementary irrigation systems, more efficient irrigation practices and adaptation and adoption of existing and new water harvesting technologies. Development of more drought and heat tolerant germplasm using traditional and participatory plant breeding methodologies and better predictions of extreme climatic events.		Thomas, 2008
General	Russia	Crop substitution Diversification of crops Expanding irrigated agricultural areas Strategic food reserves, Improving management, Monitoring and early warning systems, Food imports from abroad.		Alcamo *et al.*, ,2007,
General	Philippines	Crop diversification; change of crop varieties, use of water conservation pratices		Peras *et al.*, 2008; Lasco *et al.*, 2011
General	General	Cultivars with multiple resistance to insects and diseases		Sharma *et al.*, 2010

Table 24-8: Summary of adaptation options for securing livelihoods in Asia.

Aspect/ Issues	**Country/ Regions**	**Recommended/ Potential Adaptation strategies**	**Benefits/ Co-Benefits**	**References**
Delay and shortfall in rainfall	Indonesia	Access to credit and public works project	Able to protect food expenditure in the face of weather shocks	Skoufias *et al.*, 2011
General (droughts, floods etc)	General	Weather index insurance, cattle insurance, seed banks, credit facilities, assisted migration, cash for work	Poverty cantered adaptation, creation of assets and access to resources	Barret *et al.*, 2007; Tanner and Mitchel, 2008; Jarvis *et al.*, 2011
General	General	Assisted migration	Build financial, social and human capital	Barnett and Webber, 2010
General	Vietnam	Yield growth and improving agriculture labour productivity	Rural poverty reduction, livelihood diversification	Janvry and Sadoulet, 2010
Droughts and floods	Philippines	Bundling of improved varieties and agronomic practices and combination of production and market support	Economic benefits and social learning	Acosta-Michlik & Espaldon, 2008
General	Asia	Community based adaptation	Capture information at the grassroots, help integrating disaster risk reduction, development, and climate change adaptation, connect local communities and outsiders, and addresses the location specific nature of adaptation.	Aalst et al., 2008; Heltberg *et al.*, 2010; Rosegrant, 2011
General	Asia	Forest management	Resilient livelihoods, buffer from shocks	Chhatre & Agrawal, 2009
General	Asia	Securing rights to resources, community forest tenure rights	Resilient livelihood benefits to the poor indigenous and traditional people	Macchi *et al.*, 2008; Angelsen, 2009
Biodiversity loss	Tibet	Greater involvement of traditional and indeginous people in climate change adaptation decision making	Indigenous knowledge from the years of living in close harmony with nature	Byg & Salick, 2009; Salick *et al.*, 2009

Table 24-9: Recent publications on central Asia glaciers changes

Region	**Period**	**Initial area (km^2)**	**Area change, km^2 (%)**	**References**
Akshiirak (Inner Tien Shan)	1977-2001	406.8	-93.6(-23)	Khromova *et al.*, 2003
Akshiirak (Inner Tien Shan)	1977-2003	406.8	-35.15 (-8.6)	Aizen *et al.*, 2007
ZailiyskiyAlatau (Northern Tien Shan)	1955-1990	287.3	-81.8 (-29)	Vilesov & Uvarov, 2001
ZailiyskiyAlatau (Northern Tien Shan)	1979-1999	198.37	-34.2 (-17.3)	Bolch, 2007
Sokoluk R. basin, Kirgizkiy range (Northern Tien Shan)	1963-1986 1986-2000	31.7 27.5	-4.2 (-13.3) -4.7 (-17.1)	Niederer *et al.*, 2008
Gl.No. 1, Urumqi (Eastern Tien Shan)	1962-2003	1.94	-0.24 (-12.4)	Ye *et al.*, 2005
Terskey-Alatoo (IssikKul Lake Basin, Northern Tien Shan)	1971-2002	245	-18 (-8)	Narama *et al.*, 2006
Aksu R. basin (Kokshaaltau, Central Tien Shan)	1963-1999	1760	-58.6 (-3.3)	Li *et al.*, 2006
Kaidu R. basin (Tarim R. Basin ,Central Tien Shan)	1963-2000	333	-38.5 (-11.6)	Liu *et al.*, 2005
Central Tien Shan, Chinese territory	1960s- 1999	2093.8	-96.3 (-4.6)	Ding *et al.*, 2006
Tien Shan (all mountain system) Altai (all mountain system)	1960s-2008 1960s-2008	17,679 2,169	-1,172 (6.6%) -127 (5.8%)	Aizen, 2011
Pamir (Amu Darýa R. Basin)	1960s-2008	14,095	-671 (4.8%)	Aizen, 2011

Figure 24-1: The land and territories of 51 countries/regions.

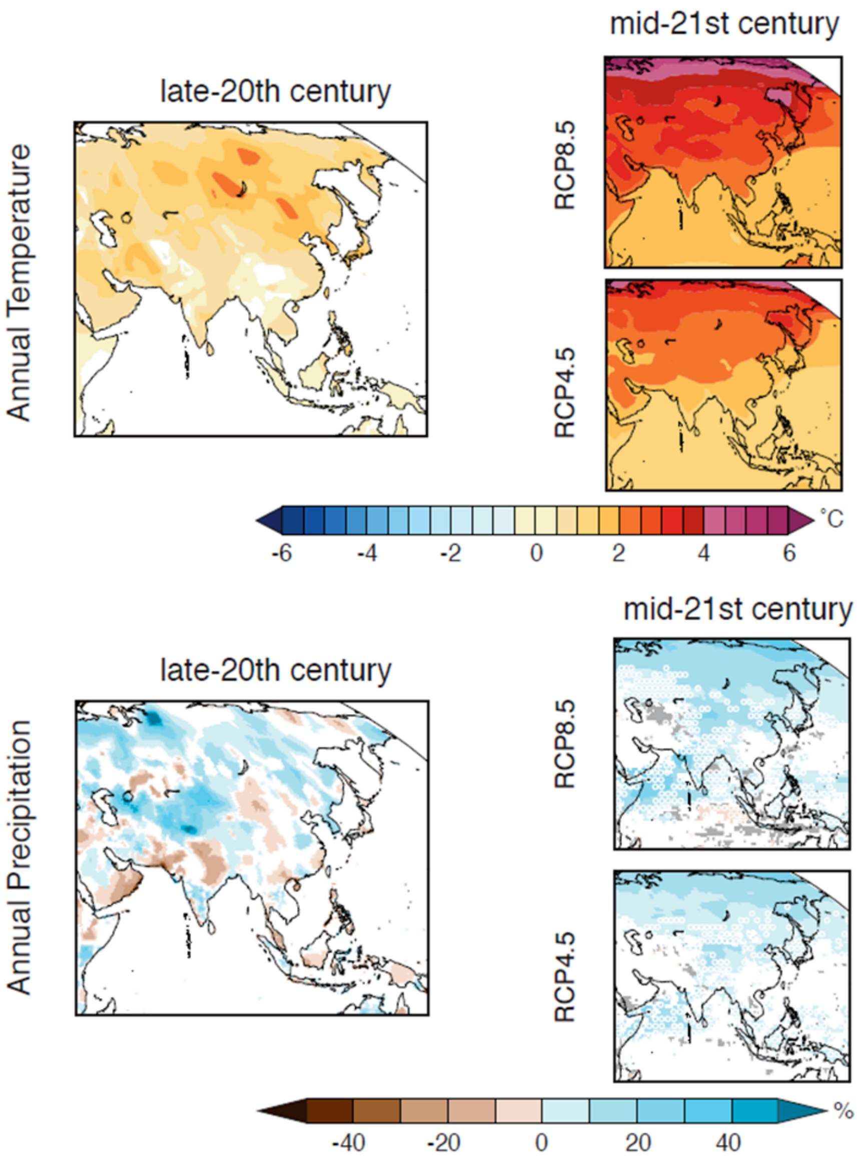

Figure 24-2: Change in annual temperature and precipitation in Asia. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.

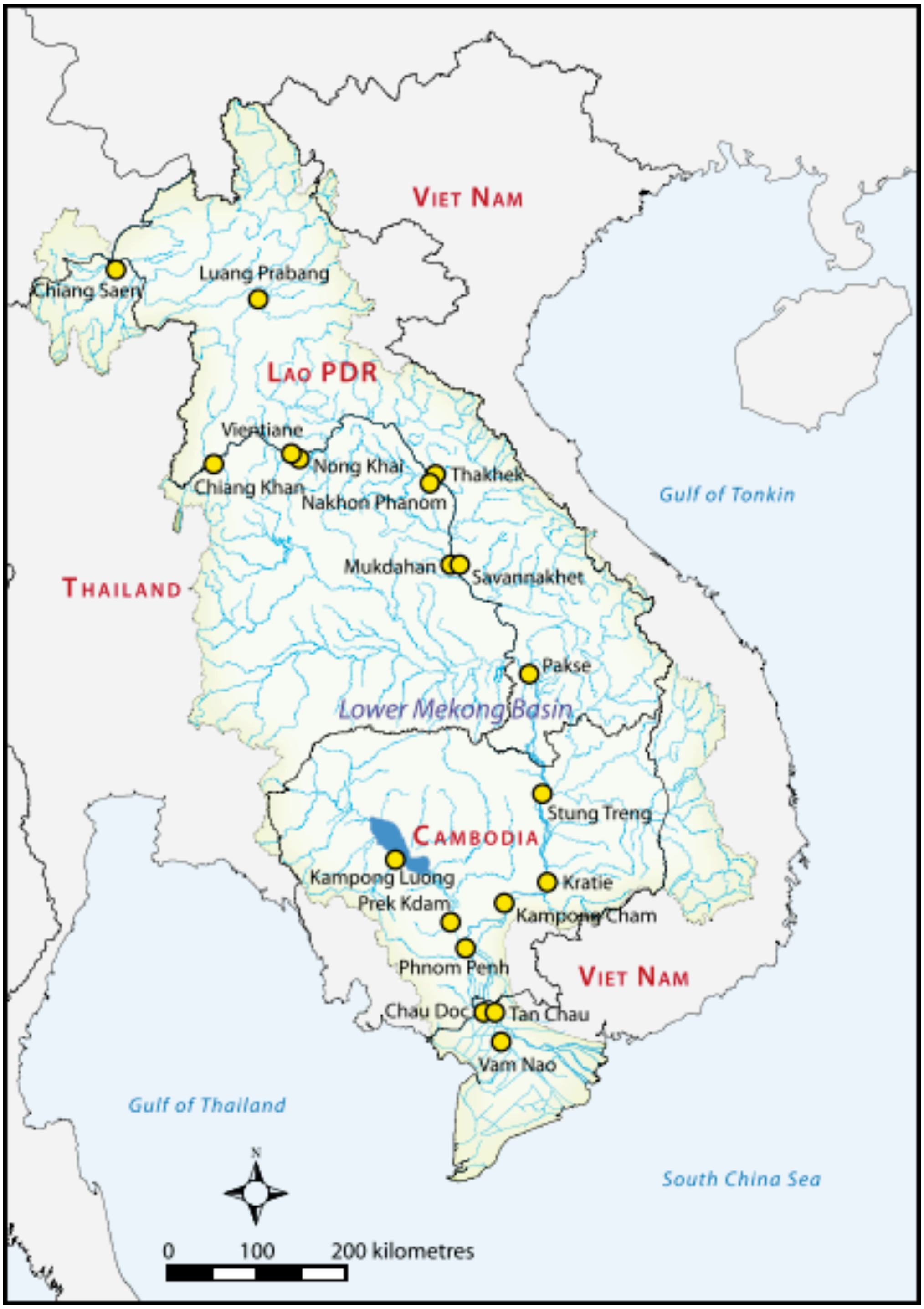

Figure 24-3: Map of Lower Mekong Basin from Mekong River Commission Technical Paper No. 24, 2009 (MRC, 2009).

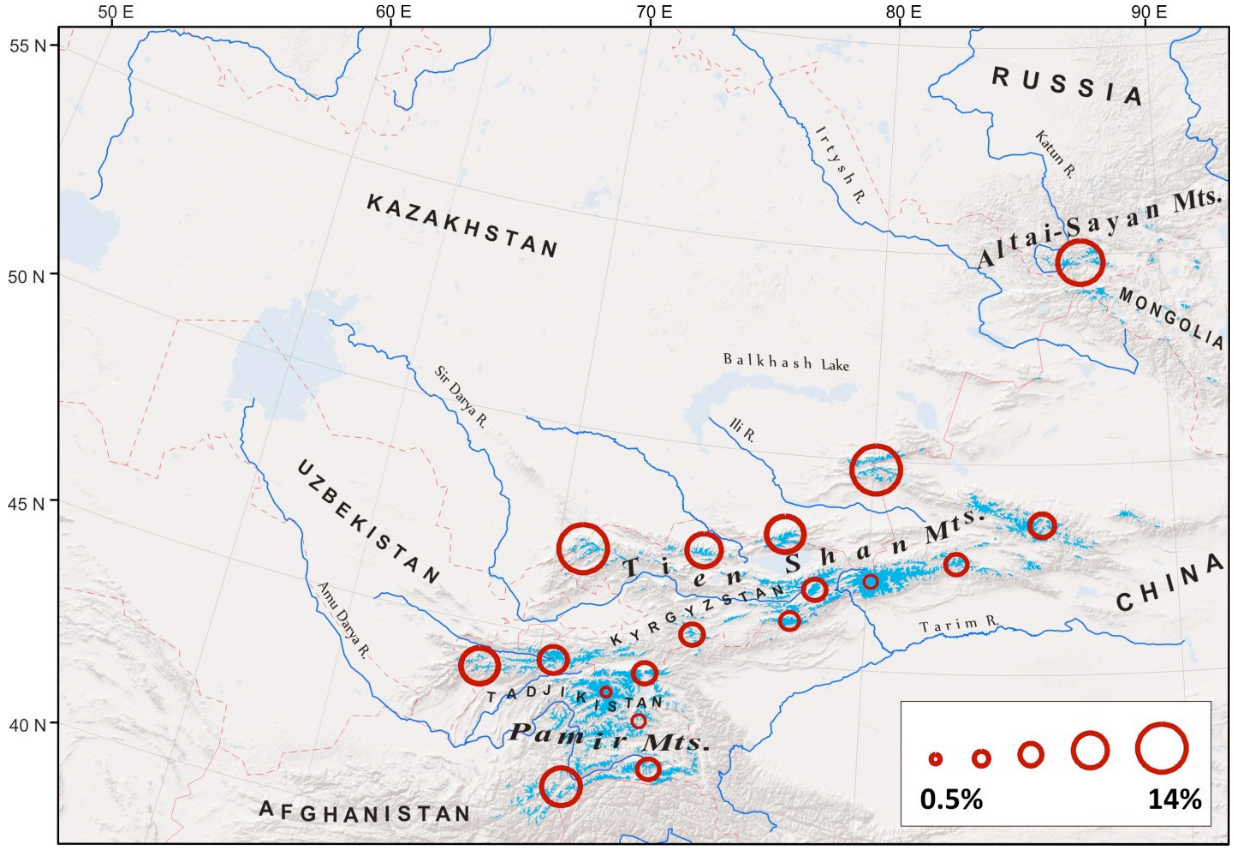

Figure 24-4: The difference in losses of glacier area in Altai-Sayan, Pamir and Tien Shan. Remote sensing data analysis from 1960s (Corona) through 2009 (Landsat, ASTER and Alos Prism).

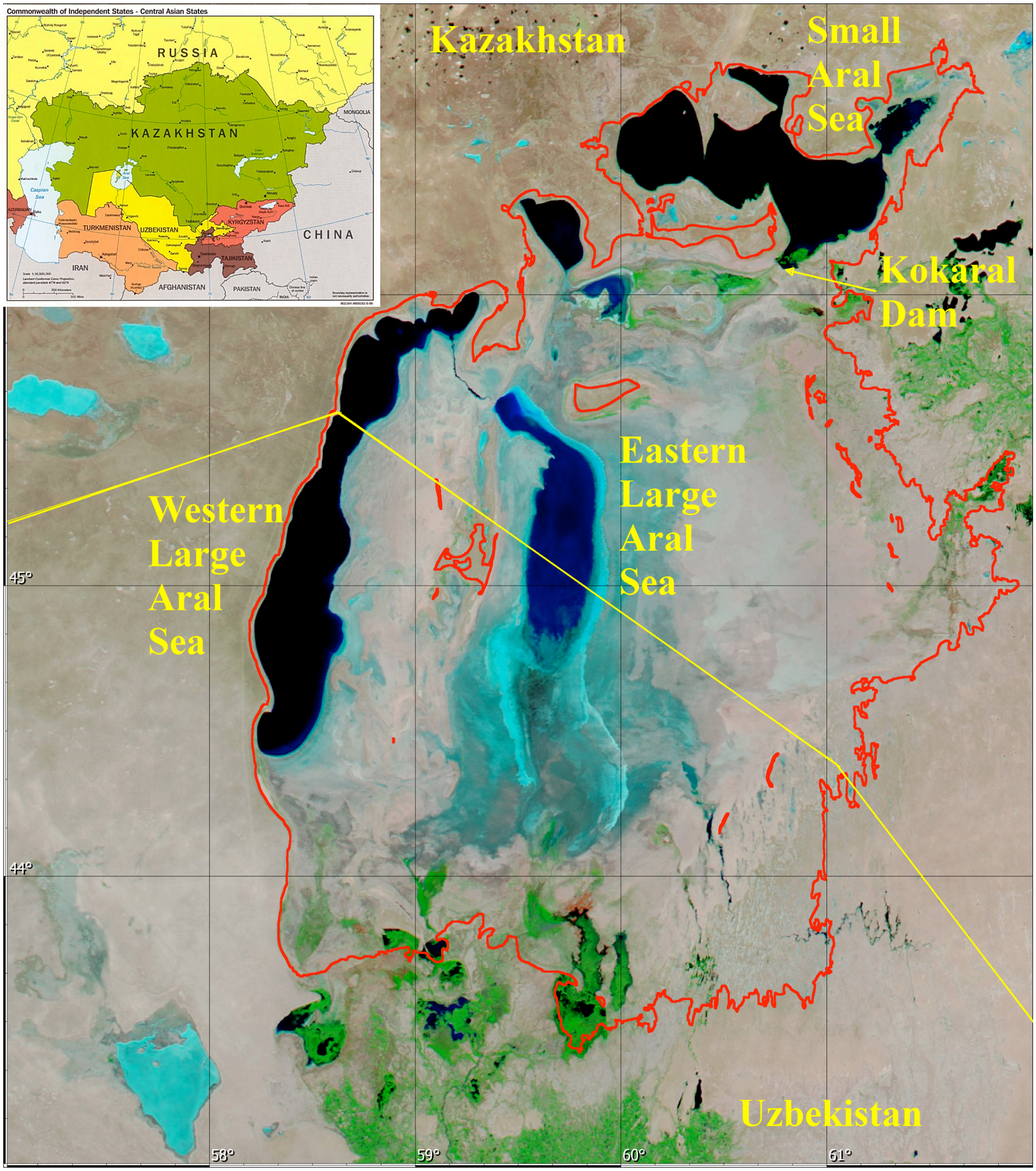

Figure 24-5: The satellite view of the Aral Sea acquired on 7 September 2012 from MODIS-Aqua. Image courtesy by A.G. Kostianoy (P.P. Shirshov Institute of Oceanology, Moscow, Russia) and D.M. Solovyov (Marine Hydrophysical Institute, Sevastopol, the Ukraine), based on the LAADS Web, NASA-Goddard Space Flight Center data (http://ladsweb.nascom.nasa.gov/). The red line indicates the Aral Sea coastline back in 1960. The yellow line indicates the border between Kazakhstan and Uzbekistan.

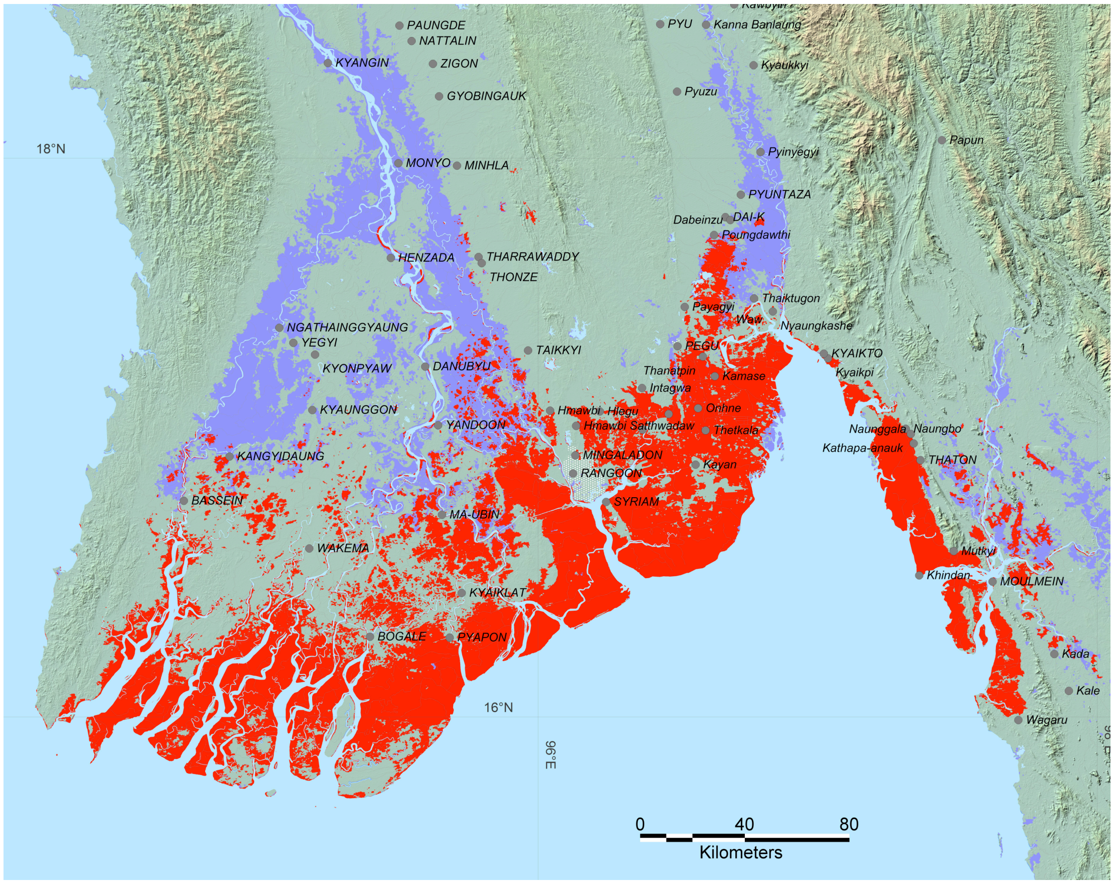

Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al*., 2012).