Chapter 24. Asia

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Executive Summary

The observed increases in annual mean temperature presented range between less than 1°C to 3°C per century in Asia, and a warming trend in daily temperature extremes was projected for much of Asia (medium confidence) have been validated again. Increasing trends in annual mean temperatures have been observed across most of Asian region including the Tibetan Plateau. Annual mean precipitation trends are characterized by strong variability, with both increasing and decreasing trends observed throughout Asian regions [Table 24-2].

Water scarcity is expected to a major challenge for most of the region due to increase of water demand and soaring water supply and lack of good management (medium confidence). Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than 1 billion people by the 2050s. Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources positively in the near future but negatively in the long term perspective. Better water management strategies are needed to ease water scarcity. Water saving technologies and changing of crops into drought tolerant crops are 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). This is evident in the case of rice production would be generally negative in many regions. 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 period. There are a number of regions that are already near the critical temperature threshold. However, with CO2 fertilization, rice yield could increase with climate change. This is also true for other crops. In Central Asia, some areas could be gainers (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters and slight increase in winter precipitation), while others can could be losers (western Turkmenistan and Uzbekistan, where frequent droughts will could negatively affect cotton production, increase water demands for irrigation, and exacerbate desertification). In the Indo-Gangetic Plains (IGPs) of South Asia, there could be up 50% decrease in the most favorable and high yielding wheat area due to heat stress at 2x CO2. There are many potential adaptation strategies such as crop breeding but research on their effectiveness is limited [24.4.4].

Terrestrial and marine ecosystems are increasingly under pressure from both climatic and non-climatic drivers; the projected changes in climate will impact natural and semi-natural vegetation， permafrost degradation spread and widespread damage to coral reefs in Asia during 21st Century (high confidence) [24.2.2, 24.4.2, 24.4.3]. The largest changes and the highest rates of change 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 more difficult to predict. Rates of 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. Permafrost degradation during the 21st century will spread from the southern and low-altitude margins, advancing northwards and upwards **(**24.4.2.3.2.**)**. Many models agree on the direction of change, but rates of change vary greatly between different model projections. 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 (Section 24.4.3.3.). 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 (Sections 24.4.3.2. and 24.4.3.3.). However the capacity of coral reefs to adjust by changes in species composition, or by the acclimation or adaptation of coral species, is not well understood.

It is very *likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels in the delta. Even most of the major deltas in Asia are now sinking at rates many times faster than the global sea-level is rising. 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. Coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea-levels [24.4.3]**.**

Extreme events will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security, forestry, health, and tourism. (high confidence) More frequent and intense heat-waves in Asia will increase mortality and morbidity in vulnerable groups; in particular in urban environments (urban heat island effect), in combination with air pollution (from wildfires, traffic, etc), or among outdoor workers in both urban and rural environments **[24.4.6].**

Multiple stresses caused by rapid urbanization, industrialization and economic development *are likely* to be compounded by climate change. Climate change is also expected to adversely affect sustainable development capabilities of most Asian developing countries by aggravating pressure on natural resources and the environment. 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 urban heat island effect) would have a number of co-benefits including public health [24.4, 24.5, 24.6, 24.7].

24.1. Introduction

Asia is defined here as the land and territories of 51 countries/regions (Figure 24-1). It can be broadly divided into six sub-regions based on geographical position and coastal peripheries (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 2009 was reported to be about 4,121 million, which is 60.3% of the world population (UN, 2009). The population density is about 130 per square kilometer (PRB, 2010). The highest life expectancy at birth is 82.7 (Japan) and the lowest is 43.8 (Afghanistan). In 2009, the GDP per capita ranged from US$492 (Timor-Leste) to US$39,738 (Japan) (World Bank, 2011). About 40% of the population in the developing countries of Asia lives below the poverty line, where their income is below US$ 1.25 per day by 2005 prices (World Bank, 2008).

[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 and variability. The observed increases in surface temperature presented in The Fourth Assessment Report (AR4) range between less than 1°C to 3°C per century, with most pronounced increases noted in North Asia [AR4, Chapter 10, 10.2.2]. In addition, the interseasonal, interannual and spatial variability in rainfall trends has been observed during the past few decades all across Asia [AR4, Chapter 10, 10.2.2]. Future projections show that warming is least rapid in South-East Asia, stronger over South Asia and East Asia and greatest in the continental interior, with most pronounced warming at high latitudes in North Asia [AR4, Chapter 10, 10.3.1]. Annual precipitation projections indicate an increase in most of Asia during this century [AR4, Chapter 10, 10.3.1]. Also an increase in extreme weather event occurrences (including heat waves and intense precipitation events) is projected for South Asia, East Asia, and South-East Asia, along with an increase of intensity in tropical cyclones in the same regions, due to a rise in sea-surface temperature [AR4, Chapter 10, 10.3.1].A warming trend in daily temperature extremes was projected for much of Asia (medium confidence) [SREX, Chapter 3, 3.3.1] No systematic spatially coherent trends in heavy precipitation have been found in most of Asia, except for a weak increase of the frequency of extreme precipitation that was observed in northern Mongolia (low to medium confidence) [SREX, Chapter 3, 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, Chapter 3, 3.3.2]. Future projections show that heavy precipitation is projected to increase in West and South Asia, as well as the Asian monsoon region, notably in Bangladesh and in the Yangtze river basin [SREX, Chapter 3, 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, Chapter 3, 3.4.1]. Increases in precipitation were projected for the Asian monsoon, while projection results for the south Asian monsoon precipitation point out to both increases and decreases in precipitation (low confidence) [SREX, Chapter 3., 3.4.1]. The coastal areas of Asia have reported that the sea level rise is accelerated relative to the long-term average and greater than the global average [AR4, Chapter 10, 10.3.1].Greatest vulnerability in terms of inundation of land area to a 1m sea level rise is located in East Asia and the Pacific, followed by South Asia (high confidence) [SREX, Chapter 3, 3.5.5].

Climate change impacts. Changes in drought patters have been reported for the monsoon regions of Asia with variations at the decadal time scale (low confidence) [SREX, Chapter 3, 3.5.1]. Studies on East Asia show increasing dryness in the second half of the 20th century (medium confidence) [SREX, Chapter 3, 3.5.1]. Other research data projects 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, Chapter 3, 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, Chapter 3, 3.5.2]. Projections point out to an increase in the risk of floods in most humid Asian monsoon regions (low confidence) [SREX, Chapter 3, 3.5.2].

24.2.2. Vulnerabilities and Adaptive Strategies

Vulnerable sectors. Crop yields in the past few decades has declined in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of El Niño and reduction in the number of rainy days (medium confidence) [AR4, Chapter 10, 10.2.4.1; Chapter 10, Executive Summary]. Studies suggest that in the future as well substantial decreases are probable not only in cereal production potential (medium confidence) [Chapter 10, Executive Summary], but also in livestock, fishery, and aquaculture net primary productivity [AR4, Chapter 10, 10.4.1.1, 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 [AR4, Chapter 10, 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 [AR4, Chapter 10, 10.4.1.4]. Changes in the hydrological cycle, and therefore also changes in the water resources have been observed with a noticeable regional variability in all of Asia [AR4, Chapter 10, 10.2.4.2]. One of the most pressing environmental problems in South and South-East 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 [AR4, Chapter 10, 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 [AR4, Chapter 10, 10.2.4.3; 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 poses a threat to the resilience of both human and environmental coastal systems, and could be additionally exacerbated by climate change [AR4, Chapter 10, 10.4.3.1]. Many plant and animal species are at risk to become extinct as a consequence of the combined effects of climate change and habitat fragmentation (medium confidence) [AR4, Chapter 10, 10.2.4.5; Chapter 10, Executive Summary]. Central, East, South and South-East 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) [AR4, Chapter 10, 10.2.4.6; Chapter 10, Executive Summary]. 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 [AR4, Chapter 10, 10.4.5]. Climate change is also expected to adversely affect 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) [AR4, Chapter 10, 10.7; Chapter 10, Executive Summary].

Vulnerable areas. Regions of South and South-East Asia were reported as vulnerable to climate change, due to the exposure of their population to severe water stress [AR4, Chapter 10, 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) [AR4,Chapter 10, 10.4.5; Chapter 10, Executive Summary]. Increases in coastal water temperature would exacerbate the risk of cholera in South Asia (high confidence) [AR4, Chapter 10, 10.4.5; Chapter

10, Executive Summary]. Crop yields in South and West Asia could decrease by a third by the middle of this century (medium confidence) [AR4, Chapter 10, 10.4.1.1, Chapter 10, Executive Summary]. Glaciers over Tibetan Plateau are projected to shrink at an accelerated pace, thus possibly increasing the number and intensity of glacial melt-related floods, slope destabilization and a decrease in river flows as glaciers recede (medium confidence) [AR4, Chapter 10, 10.2.4.2, 10.4.2.1; Chapter 10, Executive Summary]. Projected sea-level rise would result in significant losses of coastal ecosystems, along with increased risk of flooding on the coasts of South and South-East Asia (high confidence) [AR4, Chapter 10, 10.4.3.1; Chapter 10, Executive Summary]. 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) [AR4, Chapter 10, 10.4.3.2; SREX, Chapter 4, 4.4.3]. Stability of wetlands, mangroves and coral reefs around Asia is likely to be increasingly threatened (high confidence) [AR4, Chapter 10, 10.4.3.2, 10.6.1; Chapter 10, Executive Summary].

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, making changes in management philosophy, through education and the provision of climate change-related information [AR4, Chapter 10, 10.5.1]. In the water sector, dealing with water use inefficiency, and promotion of recycled water was found useful in many agricultural areas in Asia [AR4, Chapter 10, 10.5.2]. Along the coast, protection, such as dike heightening and strengthening, is considered to be important in responding to sea-level rise [AR4, Chapter 10, 10.5.3]. Most forests in Asia would benefit from comprehensive inter-sectoral programs that combine measures to control deforestation and forest degradation [AR4, 10.5.4]. Implementation of monitoring and warning systems would be helpful in reducing the impacts of climate change of human health [AR4, Chapter 10, 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 [AR4, Chapter 10, 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 [AR4, Chapter 10, 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 priority [AR4, Chapter 10, 10.5.7]. Slow change in political and institutional landscape, and existing legal and institutional framework remains inadequate to facilitate implementation of comprehensive and integrated responses to climate change [AR4, Chapter 10, 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 [AR4, Chapter 10, 10.5.7].

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 temperatures have been observed across most of Asian region including the Tibetan Plateau during the 20th century, with the warming trend continuing into the new millennium (see Table 24-2). Several studies pointed out the contribution of urban heat island to the increase in annual mean temperatures. Despite a limited amount of information, a stronger upward trend is observed for the winter mean temperatures, as compared to the summer mean in East Asia, as well as in Bangladesh, Nepal, and over eastern Khengay and across Khentey Mountains, Mongolia. On the other hand, decreasing trends were observed for the summer diurnal temperature range in North-Western part of Kashmir, India (Roy and Balling, 2005), and 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 climate trends and variability.]

Precipitation. Annual mean precipitation trends are characterized by strong variability, with both increasing and decreasing trends observed throughout Asian regions (see Table 24-2). In India, Japan, and Kazakhstan no clear national trend was observed, however, on a subnational level both positive and negative trends were observed. The amount of summer total precipitation shows an increasing trend in South-East and North-West China and a decreasing trend over Central China (Yao *et al.*, 2008).

24.3.2. Observed Changes in Extreme Climate Events

Temperature extremes. Increasing tendencies are observed in temperature extremes (see Table 24-3). Mean maximum temperatures show increasing trend in the number of warm days, and a decreasing trend in cold days has been observed throughout Asia during the late 20th century (medium confidence) (SREX, Chapter 3,Table 3-2]) Mean minimum temperatures show an increasing tendency on the continental scale, as observed in overall increase of warm nights and decrease in the number of cold nights (medium confidence) (SREX, Chapter 3,Table 3-2).

[INSERT TABLE 24-3 HERE
Table 24-3: Summary of observed changes in extreme events and severe climate anomalies.]

Heat waves. Trends in heat waves displayed noticeable regional variability (see Table 24-3). Increases in the warm spell duration index were observed overall in North Asia, in few parts of Central Asia, West Asia, and northern China, while decreasing trends were recorded in southern China, and a few areas of North Asia (medium confidence) (SREX, Chapter 3, Table 3-2).

Heavy precipitation. Regionally and sub-regionally varying trends were observed in heavy precipitation over the Asian continent, however, there is insufficient evidence or inconsistent trending for the South and South-East Asian region, as well as the Tibetan Plateau (low confidence) (SREX, Chapter 3, Table 3-2). Decreasing trends were observed for the West Asian region (medium confidence) (SREX, Chapter 3, Table 3.2).

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 (low confidence) (SREX, Chapter 3, Table 3-2). Overall tendency for increased dryness was reported in East Asia, with just a few areas showing opposite trends (medium confidence) (SREX, Chapter 3, Table 3.2).

24.3.3. Socio-Economic Scenarios for Climate Modeling

Since the AR4 was published, high-resolution (approx. range between 20-40km) GCMs or RCMs have been examined in accordance with the SRES, and the future scenarios for tropical-cyclone outbreaks and monsoon-related changes in precipitation were reported based on the GCMs/RCMs. As mentioned in Working Group I Chapter XX and Chapter XII of AR5, new climate scenarios were developed by inputting RCP data.

Under the process of assessing climate change for the purposes of AR5, scenarios of Representative Concentration Pathways (RCPs) were developed, in which the 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 (Moss et al., 2010).

As noted in Working Group III Chapter VI, the purpose of developing the four RCP scenarios was to compare the differences of climate change, climate change impacts, and emission pathways under different stabilization targets (Moss et al., 2010). In addition, Shared Socio-economic Pathways (SSPs) and Shared Climate Policy Assumptions (SPAs) have also been developed to provide the scenario elements such as Economic Growth, Globalization, Distribution/ Equity, Environmental Ethics and Values, Institutions and Governance, Technological Change and Access, Population and Demographics.

24.3.4. Projected Climate Change

The projected changes for a variety of climate parameters such as temperature, precipitation, temperature extremes, heavy precipitation, dryness, and sea levels do not show explicit regional trends (see Tables 24-4 and 24-5). Further information is being collated for specific sub-regions.

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

[INSERT TABLE 24-5 HERE
Table 24-5: Description of climate parameter abbreviations used in Tables 24-2 to 24-4.]

24.4. Observed and Projected Impacts, Vulnerabilities, and Adaptation

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 24-6). Among the countries of Asia, twenty have renewable annual per capita water resources in excess of 3,000 m3, eleven are between 1,000 and 3,000 m3, and six are below 1,000 m3 (there are no data from the remaining six countries). Hence, adequate water supply is one of the major challenges in Asia, particularly Central Asia (Vorosmarty et al., 2010). 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 fresh water supply, which will continue to decline with the decrease in precipitation, groundwater recharge and surface runoff. 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).

[INSERT TABLE 24-6 HERE
Table 24-6: Summary of observed and projected impacts in the water sector.]

24.4.1.2. Observed Impacts

Climate change have impacts on the water availability in arid and semi-arid areas (Brutsaert and Sugita, 2008), in South China (Jiang et al., 2008), in Northwest Himalaya (Bhutiyani et al., 2008). The surface water resources of Central Asia are primarily generated in mountain glaciers. Increased runoff from shrinkage of glacier is observed in Himalayas (Zhang et al., 2011) and Central Asia mountains due to increased temperature and this currently has positive impact on the water availability (Casassa, G., P. Lopez, et al., 2009; Shrestha and Aryal, 2011). Apart from water availability, precipitation is highly correlated with surface water quality, represented by dissolved oxygen, pH, conductivity (Prathumratana *et al.*, 2008 in Delpla *et al.*, 2009), dissolved salt content (Huang et al., 2009), concentrations of phosphorus related to agricultural activities (Park et al., 2010), carbon and nutrients (Zhang *et al.*, 2007b; Goldsmith *et al.*, 2008), which may increase health risk (Tornqvist et al., 2011). It is also noticeable that the water quality in groundwater is also related to climate change (Thakue and Ojha, 2010; Winkel et al., 2011; Fendorf et al., 2010). Increased frequency of flooding and droughts are also observed recently related to the climate warming. Water crisis in Asian countries is also caused by poor management (Biswas and Seetharam, 2008).

24.4.1.3. Projected Impacts

Projected impacts of future climate change on water availability (considering the future demand) in Asia differ substantially among river basins shown by 5 GCMs for A1B scenario (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 from multi-GCMs) suggest that throughout much of Russia a warmer climate would decrease water availability due to the increase of evaporation, but on the other hand precipitation would increase which tends to increase water availability (Alcamo *et al.*, 2007). In China, the projection (A2 scenario from PRECIS) suggests that there will be insufficient water for agriculture in China in 2020s and 2040s due to the increases in water demand for non-agricultural uses although positive trends of precipitation (Xiong *et al.*, 2010). In a study of the Mahanadi River Basin, the future water availability projection (A2 from 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 to its irrigation 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). Coastal fresh water resources might reduce over the next century in Asia except for South-East Asia and the vulnerable areas include South India and Bangladesh region and China while Japan stands in a good place due to its higher availability of fresh groundwater and lower population density (A2 scenario from HadCM3, Ranjan *et al.*, 2009).

24.4.1.4. Vulnerabilities to Key Drivers

It is likely that river discharge will be influenced by rainfall change, rapid melting of snow and frozen soil in the watershed (Tachibana et al., 2008) associated with the Asian monsoon change (Jian et al, 2009). Water management in river basin 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). However, they might not be able to continue the same supply because of a change in reservoir inflow due to effects of climate and socioeconomic change. On the other hand, reservoirs might have an increasing role in meeting future water requirements in regions where water stress is an issue of distribution rather than of absolute shortage (Biemans *et al.*, 2011). To adapt the climate change impact on water resource, many Asian countries apply water saving technologies in irrigation (Ngoundo et al., 2007; Tischbein etal., 2011) and other consumptive purposes (Fleskens et al., 2007), changes of crop types to drought tolerant crops (Thomas, 2008; Zhao et al., 2010), increasing water supply (Sadoff and Muller, 2009), and improved management (Kranz et al., 2010). It is found that in monsoonal Asia, development of water control systems have contributed to improved rice harvests (Hatcho et al., 2010).

For dealing with flooding, four strategies (a new flood map, an early warning system, a relief programme, and more community education) are developed in the Sarawak River system in Malaysia to reduce the excessive flood lose (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) and proposed investment 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 in water management are also suggested 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 on earth, with the predominant types differing in 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 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 above the treeline in New Guinea. Asia includes several of the world's largest river systems (Ganga-Brahmaputra-Meghna, Yangtze, Ob, Amur, Lena, Yenisei, Mekong) with their associated deltas, as well as the world's deepest and most biological diverse freshwater lake, Lake Baikal, the semi-saline Caspian Sea, and the saline and now greatly shrunken Aral Sea. Other major saline (endorheic) lakes in central and west Asia include Balkhash (SE Kazakhstan), Issyk-Kul (E Kyrgyzstan), Urmia (NW Iran), and Qinghai Lake (China).

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 (WGI AR5 ZOD). 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. Changes in inland water systems have also been widely 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.*, 2011c; Zheng, 2011).

Phenology. The most widely reported impacts attributed to the observed climate trends have been changes in the timing of life-history events, including leafing, flowering, and leaf fall in plants, the breeding periods of animals, the emergence of insects, and the arrival and departure of migrant birds (e.g. Soja *et al.*, 2007; Doi, 2007; Doi and Katano, 2008; Sokolov and Gordienko, 2008; Primack *et al.*, 2009; Fujisawa and Kobayashi, 2010; Bai *et al*., 2010; Choi *et al.*, 2011; Ge *et al*., 2011; Ogawa-Onishi and Berry, in press; Section 28.2.3.2., Chapter 28 WG2 AR5 ZOD).

Trends in phenological timing are consistent with the impacts of regional warming are widespread in northern China and Japan, including spring advances and autumn delays, particularly for plants. However, consistency is lower elsewhere and also for animals, where spring delays in phenology have been reported for some species (e.g., barn swallows in Korea; Lee *et al.*, 2011).

Plant growth, greenness and NPP. Recent changes in the growth rates of plants have also been reported (e.g. Feeley *et al.*, 2007, Nock *et al.*, 2011) and where long records are available from tree rings, these changes can be more confidently attributed to recent climate change (e.g. Duan *et al.*, 2010; Dulamsuren *et al.*, 2010a; Sano *et al.*, 2010; Yang *et al.*, 2010; Shishov and Vaganov, 2010; Li *et al.*, 2012). Changes in satellite-measured 'greenness' (NDVI) reflect changes in plant growth over larger areas. For temperate East Asia (30-80^{o}N), NDVI data show growing season length increased by 9.5 days/decade in the period 1982-2000, with the biggest change at the beginning of the season, but that part of this increase was reversed during 2000-2008 (Jeong *et al.*, 2011). On the Tibetan Plateau, warmer springs lead to an advance in greening while warmer winters cause a delay, leading to an overall delay in recent spring phenology (Yu *et al.*, 2010).

Changes in the distributions of species and biomes. Also widely reported are changes in species distributions: 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, in press) in response to recent warming. 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; Ogawa-Onishi and Berry, in press). 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).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). Soil moisture and light are the main factors governing the forest-steppe ecotone, but 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).

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 (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. This phenomenon could be attributed to increases in temperature and precipitation. Winter temperature regime is important for the Siberian pine regeneration survival. 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. Eventually, the larch in the overstorey could be replaced by these young DNC trees. 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 is another change in the forest-tundra ecotone of Northern Asia that has been attributed to climate change (Myers-Smith *et al.*, 2011; Blok *et al.*, 2011; Section 28.2.3.1., Ch 28 WG2 AR5).

The forest-steppe 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, suggesting a net loss of forest will occur in future (Dulamsuren *et al*., 2010b).

Permafrost. 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). 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; 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; 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 (see Section 4.3.4.4., Ch 4 and Section 19.3.5., Ch 19, WG2 AR5).

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.*, 2011a).

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 (MAGT) 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 MAGT in Mongolia was about 0.15°C/decade (Sharkhuu *et al.*, 2008; Zhao *et al.*, 2010).

24.4.2.3. Projected Impacts

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

Distributions of species and vegetation. The current distribution of vegetation across the region is controlled primarily by climate (particularly temperature and rainfall, and their seasonality; Tang *et al.*, 2009), 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 *et al.*, 2011b). 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. As explained in section 24.3.4, climate simulations for Asia strongly suggest that the warming trend will continue, but projections for precipitation are still uncertain. In general, the changes in both temperature and precipitation are expected to be greater in the north and west of the region, which are also the areas with the least fragmented vegetation. These changes in climate will lead to large and relatively predictable changes in the distribution of potential natural ecosystems (Ni, 2011; Wang *et al.*, 2011b; Tchebakova *et al.*, 2011; Insarov *et al.*, in press), although the transitional stages will be less predictable.

In Northern Asia, 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.* (2009) 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, a phenomenon that has happened previously in the Holocene, whereas the traditional area of larch dominance will turn into mixed taiga forest (Kharuk, 2006, 2010d). 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).

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 G.G. *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 subtropical evergreen forest will expand north into the deciduous forest zone (Wang *et al.*, 2011b). 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).

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 show that the arid northwest of the country is the most vulnerable ecoregion, with severe damage to desert ecosystems possible (Wu *et al.*, 2007, 2010). Forest is expected to expand on the more mesic parts of the Tibetan plateau and there is expected to be a general northwestern shift of all vegetation zones (Wang *et al.*, 2011a). In the drier areas of the plateau, the loss of permafrost may contribute to desertification (Cheng and Wu, 2007). In the tropics, although the expected rates of warming are less, the relatively small annual temperature range means that by the end of the century the tropical lowlands are *likely* to experience temperatures daily 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, as some projections suggest, this is *likely* to interact with forest fragmentation and logging to increase fire risk (van der Werf *et al.*, 2008).

Fewer studies have projected impacts on animals. 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 losses in bat diversity and large reductions in the distribution of most bat 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 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).

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) 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 & 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), permafrost 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 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 be ground surface drying, and land 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 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 on both living organisms and a wide range of temperature-dependent ecological, chemical, and physical processes. The dominance of ectotherms in aquatic ecosystems may make them particularly vulnerable to changing temperature, although direct evidence for this is currently lacking for Asia (Dudgeon, 2011). The other major impact of climate change is likely to be on flow regimes in running waters and consequently on riverine habitats and species that are sensitive to flow extremes (droughts and floods). Regionally threatened natural habitats that depend on seasonal inundation, including floodplain grasslands and freshwater swamp forests, will be particularly vulnerable (Maxwell, 2009; Bezuijen, 2011). 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), although non-climatic human impacts will probably continue to dominate in most Asian estuaries (Syvitski *et al.*, 2009). 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).

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 2^{o}C, 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, but the biological consequences of the predicted changes are still poorly understood. 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).

For much of Asia, increases in aridity, as a result of declining rainfall and/or rising temperatures, are the key concern. Because aridity (decreased precipitation and soil moisture and increased frequency of severe droughts) 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). Freshwater systems are also potentially vulnerable to increases in the frequency and intensity of extreme events (droughts or floods), even if average conditions are unchanged (Hamilton, 2010).

24.4.2.5. Adaptation Options

In view of the large uncertainties in the prediction of impacts and vulnerabilities, the focus so far has been largely on building resilience and enhancing the capacity of natural ecosystems for autonomous adaptation. Suggested adaptation strategies have often been generic (e.g. reducing non-climate impacts, monitoring climate impacts, maximizing landscape connectivity, making protected area networks robust to future climate scenarios; Hannah, 2010; Shoo *et al.*, 2011; Klorvuttimontara *et al.*, 2011) rather than specific to local conditions, and, in most cases, the adaptation measures adopted so far have been continuations of programs initiated for other reasons (e.g. China's "Grain for Green Program" and "Green Wall policy"; Piao *et al.*, 2010). 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 the 'geophysical stage' (i.e., habitats across the full range of physical settings, including combinations of elevation and geology); protecting 'climatic refugia' (i.e., areas where climate change is expected to be relatively attenuated); and increasing landscape connectivity (Game *et al.*, 2011). 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).

Species distribution models are increasingly used to forecast future species distributions 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.*, 2012). 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; Ishizuka & Goto, 2012). *Ex situ* conservation can provide back-up for populations and species that are most at risk from climate change (Chen *et al.*, 2009).

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 a 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.

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 (Posa *et al.*, 2011), 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 (Forbes, 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 of the 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). 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). Longer periods of annual herbivore activity are one suggested mechanism. 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 impact of warming is also evident on sparsely populated Arctic coastlines, where erosion appears to be accelerating. Permafrost and sea ice are additional factors for coastal erosion in Arctic Asia and the overall influence of cryogenic processes increases 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). 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 (WGI, Ch. 4, ZOD; WGII, Ch. 28, ZOD).

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; Neuheimer *et al.*, 2011). 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). Overall, however, the connectivity of marine habitats and the relatively high dispersal abilities of many marine organisms are expected to keep the extinction rate below that expected for terrestrial habitats (Cheung *et al.*, 2009). 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), although 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 poorly understood (Hendriks *et al.*, 2010). Warm-temperate kelp beds may be more vulnerable to catastrophic phase shifts with rising temperatures (Ling *et al.*, 2009; Graham, 2010).

The uncertainties in future sea-level rises are still large (WG1, Ch. 13, AR5 ZOD). The major projected impacts include coastal flooding, increased erosion, and saltwater intrusion into surface and groundwater. In the absence of other impacts, coral reefs could grow fast enough to keep up with rising sea-levels, 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^{o} 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). 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 increased temperature and sea-level rise, but the capacity of turtle populations to adapt is not well understood (Hawkes *et al.*, 2009; Poloczanska *et al.*, 2009; Fuentes *et al.*, 2011).

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).

It has been suggested that the warming and acidification associated with an atmospheric CO_2 concentration of 450 ppm will lead to the loss of coral-dominated reef systems (Hoegh-Guldberg, 2011). Investigations of coral reefs around natural volcanic seeps of CO_2 in Papua New Guinea suggest a much higher threshold (750 ppm) for persistence of coral cover at current water temperatures, but with severe losses in biodiversity and structural complexity (Fabricius *et al.*, 2011).

24.4.3.4. Vulnerabilities to Key Drivers

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. Polar bears, walruses, ice-associated seals, and beluga and bowhead whales may be threatened by the expected continuing decline in the extent of sea-ice in the arctic (Forbes, 2011; Kovacs *et al.*, 2011).

24.4.3.5. Adaptation Options

The connectivity of marine habitats and the relatively high dispersal abilities of many marine and coastal organisms should maximize the capacity for autonomous (spontaneous) adaptation in natural and semi-natural coastal systems (e.g., Cheung *et al.*, 2009). '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). The high carbon sequestration potential of the organic-rich soils in mangroves and peatswamp forests provides opportunities for combining adaptation with mitigation.

24.4.4. Food Production Systems and Food Security

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 generalization and new data are available especially for West and Central Asia (see Table 24-7). These differences will be apparent in the discussion below. In addition, there are now more detailed researches on the impacts to crop production. In AR4 Section 10.4.1, climate change was projected to mainly lead to reduction in yield. New research shows there will be gains as well. Depending on the regions and the crops grown, effects will vary substantially.

[INSERT TABLE 24-7 HERE
Table 24-7: Summary of observed and projected impacts in the food sector.]

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 on 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. 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, was assessed for the period of 1981–2005 (Zhang *et al.* 2010).. The study concluded that there is a variable climate to yield relationships at a regional scale. In some places, yields were positively correlated with temperature when they were also positively related with radiation. However, in other places, lower yield with higher temperature was accompanied by positive correlation between yield and rainfall.

One possible approach to generating new knowledge on 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 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 the crop water use efficiency and net photosynthesis leading to greater biomass, yield and harvest index (Ratnakumar *et al.*, 2011). 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 (350ppm to 700ppm). It was hypothesized that elevated CO_2 would produce more biomass and seed yield through an increased water use efficiency. In Yarmouk basin, Jordan, simulation with DSSAT showed that wheat and barley yields will decline by 10-20% and 4-8% respectively with 10-20% reduction in rainfall (Al-Bakri *et al.*, 2010). Increase in rainfall by 10–20% increased the expected yield by 3–5% for barley and 9–18% for wheat, respectively. However increase of air temperature had mixed results. Increasing temperature by 1, 2, 3 and 4°C resulted in deviation from expected yield by -14%, -28%, -38% and -46% for barley and -17%, +4%, +43% and +113% for wheat, respectively. These results indicate that barley would be more negatively affected by climate change and therefore adaptation plans should prioritize the arid areas cultivated with this crop.

In 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 increase of 1.5 and 3 °C would lead to wheat yields decline (by 7% and 24% respectively) in Swat district but would lead to an increase (by 14% and 23% respectively) in Chitral district. If precipitation increases by 5–15% during the growing season, the study showed a negligible impact on wheat yield.

In India, climate change impacts on sorghum were analyzed using Info Crop-SORGHUM simulation model (Srivastava *et al.*, 2010). A changing climate was projected to reduce monsoon sorghum grain yield by 2 to 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 (IGPs), a similar reduction in wheat yields is projected, unless appropriate cultivars and crop management practices were adopted by South Asian farmers (Ortiz *et al.*, 2008).

In China, a number of studies on the impacts of climate change to crop productivity 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 IPCC SRES B2 without CO_2 fertilization effect, the yield of irrigated rice along the Yangtze River decreased by 14.8%, and the yield of rain-fed rice decreased by 15.2% on average (Shen *et al.*, 2011). With CO_2 fertilization effect factored in, the 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 SRESs (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 air temperature increases of 1, 2, and 3 °C, respectively, across the stations. Other studies show similar results 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 T_{min}, T_{max}, or T_{mean}. The authors hypothesize that 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 yield overwhelmed temperature’s negative effect on rice yield.

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 was also simulation research for other crops in China. In the Huang-Hai Plain, China’s most productive wheat growing region, modeling work 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 20700-2099 due to warmer nighttime temperatures and higher precipitation, under A2 and B2 scenarios using 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.* (2010) worked on a wheat-maize cropping system in Huang-Huai-Hai (3H) Plain, China. Generally, climate change (2 and 5 ^{o}C increase in temperature; precipitation increasing and deceasing by 15 and 30%; atmospheric CO2 enrichment to 500 and 700 ppmv) would result in a mean relative yield change (RYC in %) of −10.33% with standard deviation of 20.27%, and the lowest and highest RYC values of −46% and 49%, respectively. However with CO_2 fertilization 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 of RYC for irrigated land is less negative (−18.5±12.6%) than that for rain-fed land (−21.5±14.2%). With CO2 enrichment there was no significant differences between irrigated and rainfed yield. These results show that CO_2 enrichment blurs the role 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 RegCM3 regional climate model under A2 scenario (Chavas *et al.*, 2009). Their results indicate that 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 ranging from 2.5 to 12%.

Extreme weather events are expected to further 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 chap 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 (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 it experiences (Yumul et al., 2011; Yumul et al., 2010), One study showed that relative loss per crop as part of the annual farm household income due to one tropical cyclone event for yellow corn, banana, and rice were 64%, 24%, and 27%, respectively (Huigen and Jens, 2006).

Farming systems and crop areas. Since AR4 (Section 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 crop lands 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 area suitable for growing rain-fed production of cereals and other food crops, changing sustainable stocking rates, and modifying crop irrigation requirements (Lioubimtseva and Henebry, 2009). The region is expected to become warmer during the coming decades and increasingly arid across the entire region, especially in the western parts of Turkmenistan, Uzbekistan, and Kazakhstan. The impacts to food production will vary by country. Some parts of the region could be gainers (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). Agricultural production in general depends on honey bees (*Apis mellifera*), but honey 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 (IGPs) are under threat of 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 current population), who’s 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 are more vulnerable to the adverse impacts of climate change than those 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 of variation in the cropping season as compared with that at present; thus, resulting in a reduction in the frequency of cool summer damage in the northern districts. 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 ≈ 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. Second, the extraordinarily dry conditions in JAS could preclude the planting of rice and all other crops without irrigation during these months by 2050. In Sri Lanka, studies on rice production have mixed results (Eriyagama *et al.*, 2010). An earlier study showed that a 0.1-0.5°C increase in temperature could depress rice yield by approximately 1-5%. However, another experiment suggested that rice yields 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 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, irrigated rice production is projected to be positive in the extreme south of the country, confirming results of a previous study. However, the impacts are 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 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 HadAM3H GCM and PRECIS regional model, especially under the A2 scenario. The proportion of water demanded by rice (which consumes 79% of 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 by 3% and 16%, respectively under B2.

Livestock, fishery, aquaculture. Since AR4, very limited information has been added on the impacts of climate change on livestock, fishery, and aquaculture. In Mongolia, Marin (2010) showed that both local knowledge of herders and meteorological data and projections are important in assessing the impacts of climate change as well as potential adaption strategies. While regional models and local analyses agree that Mongolia has become warmer, predictions either ignore or are contradictory about the changes in precipitations and sand storms. The nomadic herders of Mongolia demonstrated a detailed understanding of weather and climate. According to the herders, the dust storms and droughts were more frequent and severe, rains were patchier, less effective (‘harder’) and delayed. All of these could affect livestock production in the country.

Future food supply and demand. AR4 Section 10.4.1.4 was largely based on global models including Asia. Since then there are now a few quantitative studies on the whole continent and countries. In general, these studies 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 B1would 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, 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 in the same year 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 SRES. The increasing shortfalls was 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.

Likewise, most of the studies reviewed in the previous sections show negative impacts of climate change to crop yield and therefore presumably on food supply. In contrast, climate change may also lead to increase food supply of 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)/year in the mountain areas (Hussain and Mudasser, 2007). It will also allow more time for land preparation of 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 on climate change and pests and diseases which support the aforementioned conclusion. For example in South Asia, warming temperatures could lead to higher incidence of spot blotch (caused by Cochliobolus sativus), already a serious constraint to wheat production at present. An increasing mean minimum temperature in March showed a positive relationship with spot blotch severity (Sharma *et al.*, 2007). In the future, Sharma *et al.* (2010) recommended the need to regularly monitor pest populations 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.

24.4.4.4. Vulnerabilities to Key Drivers

Vulnerability of rainfed agriculture is expected to increase with decreasing precipitation. However, decreasing availability of water due to economic and population growth will negatively influence the irrigated agriculture as well. Rapid population growth will raise food demand, and further industrialization of developing countries could lead to massive migration from rural areas into urban ones. One cannot ignore the impact of governmental decision, such as land policies, or improvements in agricultural technologies, and market oriented land-management, which can affect the efficiency and scale of cultivated land. Due to this plurality of factors in determining vulnerability of the food production systems it is becoming more and more difficult to ascertain a clear picture of future climate change impacts.

24.4.4.5. Adaptation Options

Since AR4, there have been additional studies on recommended and potential adaptation strategies and practices in Asia (see Table 24-8). There is new information on West and Central Asia. There are also much more crop specific and country specific adaptation options available.

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

It is noteworthy that farmers have been adapting to climate risks for generations. Indigenous and local adaptation strategies have been documented Southeast Asia (Peras *et al.*, 2008; Lasco *et al.*, 2011; Lasco et al., 2010). These strategies could be used as a basis for future climate change adaption. In addition, social and institutional aspects of climate change adaptation have also been investigated in the Philippines. Agent-based modeling showed that small holder farmers face a number of constraints in adapting new technologies to cope 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. It is interesting that in the above studies there are many non-farm related adaptation strategies. Local government units (LGUs) can also play a catalytic role in climate change adaptation as shown by the experience of Albay province in the Philippines (Lasco *et al.* 2008).

24.4.5. Human Settlements, Industry, and Infrastructure

24.4.5.1. Sub-Regional Diversity

Asia, being the largest continent of 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 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. For example, two sub-regions i.e. East Asia and South-Central Asia, account for 80% of the continents population (UNFPA, 2010). At present 69% of the world’s rural population is highly concentrated in a few Asian countries. India and China has the largest rural population amounting to 45% of the world’s rural population, followed by Bangladesh, Indonesia and Pakistan each with over 107 million rural inhabitants. Much of the increase projected in the world population is expected to come from 39 high-fertility countries of which nine are located in Asia. Notwithstanding this, population growth rates have been decreasing in almost all sub regions of Asia since 2000 (UN ESCAP, 2011).

Presently, about one in every five urban dwellers in Asia lives in large urban agglomerations and little less than 50% of urban dwellers live in small cities (UN, 2012). However, there is wide sub-regional level variation. For example, North and Central Asia are the most urbanized areas where over 63% of the population live in urban areas with the exception of Kyrgyzstan and Tajikistan, followed by East and North-East Asia where rapid urbanization in last two decades led to 50 % population living in cities by 2010 (UN ESCAP, 2011; UN Habitat, 2010). South and South-West Asia are the least urbanized sub-regions with only 33% of the population living in urban areas. However, the sub-region has the highest urban population growth rate 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 that alone 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). Across all the sub-regions 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.

24.4.5.2. Observed Impacts

Asia experienced the highest number of weather- and climate-related disasters during the period of 2000 to 2008 and suffered huge economic loss, accounting for the second highest proportion (27.5%) of total global economic losses.

Loss of human lives, cultural heritage, and ecosystem services, are difficult to value and monetize, and thus are poorly reflected in estimates of losses. Impacts on the informal or undocumented economy, as well as indirect effects, can 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 [see Figure 24-2]. The top ten countries at risk of floods (based on number of lives lost) are India, Bangladesh, China, Viet Nam, Cambodia, Myanmar, Sudan, Korea, Afghanistan and Pakistan (UNISDR, 2009). Severe floods of July 26, 2005 in Mumbai, which happened after receiving 944 mm rainfall within 24 hours is attributed to both climate as well as non-climate 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., 2010).

[INSERT FIGURE 24-2 HERE
Figure 24-2: Hazard mortality risk.]

On the contrary, in many parts of Asia, there exist seasonal shortfalls in the availability of water, which is also a growing crisis (ADB, et al., 2012). Despite the increasing number of people living in floodplains, strengthening of capacities to address the mortality risk associated with major weather-related hazards (e.g. floods), mortality risk relative to population size is showing downward trend, such as in East Asia and the Pacific, where mortality risk is now at a third of its 1980 level (UNISDR, 2011).

24.4.5.3. Projected Impacts

About half to two-third of Asian cities with 1 million or more population are located in regions exposed to natural hazards (UN, 2012). The possibility is high for underestimating the impact of rare or more severe natural disasters on urban areas. Asian mega-deltas are susceptible to extreme impacts due to a combination of high-hazard rivers, 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 in 2011 are located in areas with high risk of floods. They are Tokyo, Delhi and Shanghai (UN, 2012). Flood risk and associated human and material losses are heavily concentrated in India, Bangladesh, and China. East Asian region in particular experienced increasing dryness, affecting its socioeconomic, agricultural, and environmental conditions negatively, which is attributed to lack of rains, high evapotranspiration as well as over-exploitation of water resources. Increase in climatic and weather extremes is expected to aggravate the problem of pollution and flooding. While most urban centers in Asia have no sewers, aging infrastructure may hinder the presently operational 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 direct influence on urban and rural settlements, infrastructure and industries alike. Large parts of South, East and South-east Asia is exposed to higher degree of cumulative climate related risk (UN-Habitat, 2011).

In absolute terms, Asia has more than 90% of the global population exposed to tropical cyclones (IPCC, 2012). 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 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.

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 are estimated, taking into account scenarios of socio-economic and climate changes (Hanson *et al*. 2011). 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 especially in the next century (Becker *et al.*, 2011). There is consensus that planned rapid expansion of ports should take into account adaptation measures as ports construct new infrastructure that may still be in use at the end of the century.

Population and Assets. 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, 2008).

Cities susceptible to human-induced subsidence (mainly, developing county cities in deltaic regions with rapidly growing populations) could see significant increases in exposure due to human-induced subsidence as shown historically in several Asian cities (Nicholls, 2008).

Settlements on unstable slopes or landslide prone areas face increased prospect of rainfall induced landslides. Disturbance in water-cycle due to changing climate is already affecting agriculture output but also resulting into serious socio-economic problems forcing people to either fall into vicious circle of poverty or migrate.

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 usually high-quality water supply in cities of developing countries, are threatened due to over withdrawals. Aquifer levels have fallen by 20 to 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.

The impacts on human settlements and living facilities can be summarized as: (i) increasing shortage of water resources, climate change has been shaping the Yangtze River Delta and its socioeconomic development (Immerzeel, 2010; Vineis, 2011; Shrestha, 2011; Gu et al., 2011; Kang, et al., 2009); (ii) growth in health care expenditure (Ebi et al., 2007; McBean, 2009); (iii) impact on seasonal tourism, the simulation results from seven Japanese ski grounds show that the temperature increase of 3 degree Celsius will cause 30 percent decrease of skiers (Chunyan, et al, 2010; Jianming,et al., 2010; Jian-chao et al., 2011); (iv) impact on livelihoods, the combination of social impacts (e.g. loss of livelihood, displacement) and economic impacts (e.g. damage to industry) could have cumulative or multiplicative effects that eventually interfere with the function and activity of communities within urban areas (Lioubimtseva et al., 2009; Binyi, et al., 2010; Gasper, et al., 2011); (v) physical and mental health of residents that is closely related to climate change, where cold climate easily causes depression (Jin-qi, et al., 2010; Yingjun, et al., 2010; Yonghing, et al. 2008).

Industry and Infrastructure. The impacts of climate change on industry include the direct impacts on industry production and the indirect impacts on industrial enterprises due to the implementation of the mitigate 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 the greater impact on large and medium-sized construction projects (Kim, 2007).

Climate change 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 on local economies "and strip populations of their assets and livelihoods", in some cases leading to mass migration. 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" (UN-Habitat, 2011).

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 increase in income disparities, but can also weaken resilience to climate extremes. ADB reported that in the last two decades, 11 economies of Asia, which account for more than four-fifths of the region's population have also experienced widening gap between rich and poor (ADB, 2012). These development challenges can negatively affect 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 creating both localized heat-island effect as well as flooding in dense urban built environments. UN-Habitat (2011) informs 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.

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 2,305 million), and suggests adaptation measures to reduce future damages (Ranger, et al., 2011).

The massive investment 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 regret' 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". A comprehensive approach featuring non-structural flood control measures is essential for effectively addressing future flood risks in complex urban systems (see Table 24-9). Adaptation measures such as improvement of city's drainage system 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).

[INSERT TABLE 24-9 HERE
Table 24-9: Summary of adaptation options.]

The role of urban planning and urban planners is emphasized towards adaptation to climate change impacts (IPCC, 2012; Fuchs, 2011). City planners with greater understanding of climate change related hazards and capable to communicating associated risk can effectively utilize spatial planning and social infrastructure as tools for adaptation in cities (Fuchs, et.al. 2011). Climate sensitive urban planning is effective even as long-term adaptation measure if takes into account climate variability including uncertainty, and systems vulnerability and capacity (IPCC, 2012).

Awareness, improved governance, development and local partnerships are essential for promoting resilience and adaptation. This is reflected by the significantly different number of fatalities experienced from the impacts of cyclones Sidr and Nargis in developing Asian countries (IPCC, 2012) and in reducing flood risks in Mumbai.

Green infrastructure is an important new role in protecting urban areas from the consequences of inevitable climate change (Barber, et al., 2009). Climate change brings a significant effect on the building’s cooling and heating load, electricity consumption and the outdoor design conditions for air conditioning systems (Yau, et al., 2011). Climate change is expected to influence the demand for space cooling and heating (Vuuren, 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 total population in these countries and contributes to 15.3% of total value added GDP (FAOSTAT, 2011; World Bank, 2011a). Asia also has high levels of rural poverty compared to the urban poverty, with relatively higher poverty incidence in the 8 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).

Though 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, 2011b). In terms of developmental 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 (United Nations, 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 due to 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; Solberg, 2010), invasions of mosquitos (Pawar *et al.*, 2008), and exposure to rodent-borne pathogens like hantavirus and Leptospira (Kawaguchi *et al.*, 2008; Zhou *et al.*, 2011). Contaminated flood waters in urban environments have caused exposure to pathogens and toxic compounds, as noted in e.g. India and Pakistan (Sohan *et al.*, 2008; Warraich *et al.*, 2011). Mental disorders and posttraumatic stress syndrome are 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 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). Linear correlations between temperature rise and mortality have been shown for India (McMichael *et al.*, 2008) and several cities in East Asia (Chung *et al.*, 2009; Kim *et al.*, 2006). Several studies have analyzed 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 heatwaves 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 increase the exposure to sand and dust, often mixed with toxic compounds (Wang *et al.*, 2011). There are indications that dust storms in South West, Central and East Asia increase hospital admissions and worsen asthmatic conditions, as well as cause skin and eye irritations (Griffin *et al.*, 2007; Hashizume *et al.*, 2010; Kan *et al.*, 2011; 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).

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 of China (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).

Vector-borne diseases. Increasing temperatures affect vector-borne pathogens during the extrinsic incubation period and shortens the life-cycles of arthropod vectors, thereby facilitating for larger vector populations and enhanced disease transmission. Several Asian studies have focused on the emergence of dengue fever. Outbreaks have been correlated with temperatures and rainfall (Sriprom *et al.*, 2010; Hsieh and Chen 2009, Nitatpattana *et al.*, 2008; Shang *et al.*, 2010; Su, 2008), in one study with linear correlations with a time lag of 1-3 weeks (Hii *et al.*, 2009). 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 *et al.*, 2006; Laneri *et al.*, 2010), whereas temperatures were linked to malaria distribution and seasonality in Saudi Arabia (Kheir *et al.*, 2010). Re-emergence of malaria in central China has been suggested to be explained by rainfall and increases in temperature close to water bodies (Zhou *et al.*, 2010). Temperature, precipitation, and virus-carrying index among rodents have been found to be correlated to the prevalence of hemorrhagic fever with renal syndrome in China (Guan *et al.*, 2009; Yan *et al.*, 2008).

Livelihood and Poverty. There have been significant changes in terms of livelihood diversification in Asia over the decades due to rapid economic development (see Table 24-10). Estimates suggest that currently about 51% of total income in rural Asia come from non-farm sources (Haggblade et al., 2010; Haggblade et al., 2009), out of which 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 improvement in poverty eradication over the past decade (World Bank, 2008). At the sub-regional level, the East Asia has recorded much rapid reduction in poverty followed by South Asia (IFAD, 2010). Significant part of this reduction has come from population shift, rapid growth in agriculture, and urban contribution (Janvry and Sadoulet, 2010).

[INSERT TABLE 24-10 HERE
Table 24-10: Summary of observed changes and projected impacts for livelihoods and poverty.]

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, i.e. the elderly, and 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 show 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).

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 e.g. West and South Asia (Husain and Chaudhary, 2008; Garg *et al.*, 2009; Majra and Gur, 2009). Some studies have developed climate change-disease prevalence models, for example for schistosomiasis in China that shows an increased northern distribution range of the disease with climate change (Kan *et al.*, 2011, 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 and droughts and changes in seasonal rainfall patterns are expected to negatively impact crop yields, food security and livelihood in vulnerable areas (Dawe *et al.*, 2009; 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 increase in food price and cost of living (Hertel et al., 2010; Rosegrant, 2011). Poverty impacts of climate change would be heterogeneous among countries and social groups [see Table 24-10]. In low crop productivity scenario, food exporters such as Indonesia, Philippines and Thailand would benefit from climate change related global food price rise and be able to reduce poverty while countries such as Bangladesh would experience a net increase in poverty to the tune of 15% by 2030 (Hertel et al., 2010). Regression studies conducted by Skoufias et al. (2011) indicate significant negative impacts of shortfall in rainfall on the welfare of rice farmers in Indonesia, compared to the delay in 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).

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 the vulnerability of livelihoods in agrarian communities also arise 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, 2009;

Salick et al., 2009; Xu et al., 2009; Winters et al., 2009; United Nations, 2009). Urban wage labourers were found to be most 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 forest and landfires; for example vulnerability of agriculture, forestry and human settlements on peat land areas in Indonesia (Murdiyarso and Lebel, 2007). Human health is also a major area of focus for Asia (Munslowa 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.

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, 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 shown to be successful in preventing deaths among risk groups, like in Shanghai (Tan et al 2007). Also proven successful are the implementation of new work practices to avoid heat stress among outdoor workers, as shown in studies from Japan and 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 e.g. Thailand (Kim Oanh and Leelasakultum, 2011). Early warning models are also being tested in infectious disease prevention and vector control programs, like for malaria in Bhutan (Wangdi *et al.*, 2010) and Iran (Haghdoost *et al.*, 2008), or are being developed, like for dengue fever region-wide (Wilder-Smith *et al.*, 2012).

Available literature suggests the need for identifying and promoting technologies and policy options that will provide both mitigation potential as well as sustained income generation potential in a changed climate (Bhandari *et al.*, 2007; Rosenzweig and Tubiello, 2007; Paul *et al.*, 2009). 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 introduction of traditional flood mitigation measures in China could positively impact the local livelihoods leading to both reductions of physical and economic vulnerabilities of communities (Xu *et al.*, 2009). Significant amount of literature has stressed for 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 the 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 were 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 24-11). In general, greater emphasis on agriculture 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), 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 addresses 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 24-11 HERE
Table 24-11: 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 attention to the research efforts of assessing aggregate costs of climate change impacts and adaptation. There are a few studies focusing on disperse sectors though without comprehensive economic valuation of the costs and benefits of adaptation. Examples of such studies include exploring low-cost adaptation strategies to reduce the net vulnerability of sorghum production system 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 simulation 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 (ADB, 2009) with focus on Indonesia, Philippines, Thailand, and Vietnam 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 of IPCC, 2000), 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 the agriculture and coastal zones (mainly the construction of sea walls and development of drought- and heat resistant crops) would be about $5 billion/year by 2020 on average, and that this investment would be paid in the future. For instance, the annual benefit of avoided damage from climate change is likely 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 CO2 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). Assisted migration may be useful for some species in fragmented landscapes (Thomas, 2011). More generally, conservationists may need to consider abandoning the current focus on the preservation and restoration of 20th century reference conditions, which may no longer be relevant in a changing world (Thomas, 2011).

24.5.2. Flood Risks and Coastal Inundation

Many coastal areas in Asia are anticipated to face threats of flood risk and coastal inundation exacerbated by climate change. Responding to a large number of climate change impact studies for each country over the past decade (e.g. Huang et al., 2004; Karim and Mimura, 2008; Pal and Al-Tabbaa, 2009), 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 identifying policy options with Geographical Information System (GIS). As a matter of course, these have been developed for flood risk management so far, most of the tools have begun to give consideration in varying degrees to climate change impact such as sea level rise in long term.

In India, for example, coastal vulnerability index for mainly sea level rise were calculated and mapped to inform the vulnerability in each area of the west coast (Dwarakish et al., 2009), and physical and social vulnerability to storm surge considering climate change ware mapped in each area of the east coast (Rao et al., 2010). In Bangladesh, a positive relationship between flood risk, poverty and socioeconomic vulnerability was identified and an importance of preparedness of the poor household and support from community were indicated from a case study on the southeast region (Brouwer, et al. 2007). In Indonesia, involvement of stakeholder and community were proposed to improve the existing flood risk management from a case study in outlying city of Dhaka (Marfai and King, 2008), and actually community based vulnerability assessment was implemented to identify various adaptation measures (Taylor, 2011). The similar approach was conducted in the central province in Vietnam. Integrating technology like GIS and indigenous local knowledge through the participatory technique was stressed in this case (Tran et al., 2009). Also in Ho Chi Minh City in Vietnam, intensive approach to integrate climate change adaptation policy and urban planning is in progress providing a toolkit which aims at the empowerment of local decision makers and other relevant actors providing a broad range of potential options for climate change adaptation policy (Schwartze et al., 2011; Storch et al, 2011).

All these tools and systems tend to have a direction of community-based approaches. These approaches have been salient over the past two or three decades in environmental policy, disaster risk management and so on. Behind these backgrounds, there is a growing recognition that such approaches are indispensable to reduce vulnerability and to build adaptive capacity effectively. However, a key challenge for a successful implementation of community-based approaches is to keep it easy enough for wider application (Van Aalst, et al. 2008). Also it requires an understanding of the community structure and other factors while the approaches have primary weakness of lack of resource and decision-making, legislative and regulatory powers available to local-level actors (Allen, 2006). One of the key components to overcome the weakness is social capital. In Vietnam, climate change adaptation strategies were facilitated by social capital that emerged in the absence of governmental support or frameworks (Adger, 2003). It implies that community-based approaches have possibilities to vary depending on works of social capital in the context of the community.

24.5.3. Economic Growth and Equitable Development

Economic, social, and environmental equity is an enduring challenge in many parts of Asia. Attempts have been made to use the level of wealth (typically GDP) as a measure of human vulnerability of a country or region, but this approach has serious limitations. In many cases, social capital, an indicator of equity in income distribution within countries, is a more important factor of vulnerability and resilience than GDP per capita. 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 taken significant steps in taking into account climate change adaptation in their loan and grant making process (Gigli and Agrawala, 2007; Klein *et al.*, 2007b). In contrast, in developing countries, actual projects on the ground to mainstream adaptation to climate change remains limited and significant institutional and cognitive barriers remain (Yohe *et al.*, 2007; Gigli and Agrawala, 2007). For example, in the Philippines, the reasons that hindered climate change mainstreaming are the following: national priorities are geared towards what are perceived to be more pressing concerns such as employment generation and education and a pervasive lack of awareness on the impacts of climate change to sustainable development (Lasco *et al.*, 2009). However, there are massive investments on 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. This can include lack of financial resources for adaptation implementation, institutional barriers, biophysical limits to ecosystem adaptation etc. (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 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 be as a result of climate change but also weak governance mechanisms and breakdown of policy and regulatory structures, especially in the context of common-pool resources (Moser and Ekstrom, 2010). Furthermore, this impact depends on the inherent vulnerability of the socio-ecological systems in a region, as much as on the magnitude of climate impact (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 young professional development in the field of climate change adaptation, it is of utmost importance to include the topic in the higher education, especially in the formal education programs. Shaw et al. (2011) emphasized the need of 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 adaptation and risk reduction. Similar needs in the Asia-Pacific region 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, internship, and establishing education-research linkages by exposing the students to field realities. In this regard, a few guiding principles should be: inclusive curriculum, 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. Intra-regional and Inter-regional Issues

24.6.1. Trade and Economy

A well-functioning international trading system can support the adaptation to climate change-related challenges. 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 a greater impact on the Indonesian economy compared to IJEPA (Indonesia–Japan Economic Partnership Agreement) while the adoption of both agreements contributes to increasing CO2 emission by 0.47% compared to the BAU case. This is mainly due to a high emission coefficient by the transportation sector. On the other hand, the agreements did have a positive impact on water pollution indicators.

China's high economic growth flourishing trade activities on both domestic and international levels have resulted in significant amounts of water withdrawal and water pollution. For instance, Guan and Hubacek (2007) found that North China as a water scarce region virtually exports about 5% of its total available freshwater resources while accepting large amounts of wastewater for other regions' consumption. By contrast, South China a region with abundant water resources is virtually importing water from other regions while their imports are creating waste water polluting other regions' hydro-ecosystems. Thus, the effective trade liberalization and regional trade policy might be useful to mitigate some of major climate change challenges affecting the environment and health such as air pollution, water scarcity and security as well as waste management.

24.6.2. Migration and Population Displacement

Migration has received attention in the literature as an adaptation option (Reuveny, 2007; Warner, 2010). Studying environment and other natural resources-induced migration can help to effectively manage climate change induced migration (Reuveny, 2007). 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). Rapid-onset environmental change such as floods, as in the case of Mekong Delta, are increasingly playing a role in migration (Warner, 2010). These migration induced remittances have significantly contributed to Asian economies and decreased the poverty gap but had negligible effect on poverty rate (Vargas-Silva et al., 2009).

24.7. 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 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 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) are likely 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). 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 in e.g. 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.

Ecological adaptation measures that increase plant biomass, 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 at the same time they decrease biodiversity and contribute less to ecological services. Biodiversity-rich carbon storage that is resilient to future climate change would be a more sustainable choice (Díaz et al., 2009). The potential for both adaptation and mitigation through forest restoration appears to be greatest in the tropics (Sasaki et al., 2011). In boreal and high latitudes temperate regions it will also be necessary to consider albedo effects, with the possibility that adaptation-driven reforestation could have negative consequences for mitigation by reducing surface albedo (Thompson et al., 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 will often 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.

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 through 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 (coal) 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 in particular in urban environments as projected in India (Woodcock et al., 2009). The use of more public transportation as well as active (bicycling, walking, etc) transports and less 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 emission reduction programs in China (Wu et al., 2011) and in 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. In a number of cases, from Dubai and Abu Dhabi in the western part of the region to Singapore in the eastern part of the region, Asia is becoming a test bed for innovative applications of technologies that are at the frontier of new energy pathways for sustainable development.

There has also been emphasis on forests and their management for providing resilient livelihoods and reduce poverty (Persha et al., 2010; Larson, 2011; Noordwijk, 2010; Chhatre and Agrawal, 2009). Securing rights to resources was found essential for greater livelihood benefits to the poor indigenous and traditional people (Macchi et al., 2008) for which REDD+ schemes have been urged to respect and promote community forest tenure rights (Angelsen, 2009). It was 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 that may keep communities in perpetual poverty (Campbell, 2009). Among financial means, low-risk liquidity options such as microfinance programs and risk transfer products can help lift rural poor from the poverty and accumulate assets (Barret et al., 2007; Jarvis et al., 2011).

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Box 24-1. Rice-Wheat Systems in India

Autonomous adaptation may have undesirable impacts. This case shows how adaptation actions today may negatively impact the possibility of future adaptation. In the rice-wheat systems on the Indo-Gangetic plains rice is planted in July, harvested in October-November and then wheat is planted in November and harvested in April. If there are any delays in the system, or if as a result of changing weather patterns temperatures are higher, wheat yields are reduced due to increased temperature during grain filling in March and April. To avoid this, farmers need to plant wheat immediately after rice. Some farmers therefore burn rice residues to vacate fields and to plant wheat in time. This unfortunately increases GHG emissions. Minimum tillage approaches may be appropriate in these circumstances, though incentives to farmers to adopt such practices will need to be put in place.

_____ END BOX 24-1 HERE _____

24.8. Research and Data Gaps

There are still regions within Asia that are not sufficiently represented in observed climate change studies, 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 study 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 (Wright *et al.*, 2009). 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.*, 2009; 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 methods intercalibration (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 CO2 fertilization, regional effects (Shuang-1 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 CO2 fertilization.

There is a need to increase the knowledge on heat and air pollution interactions and health effects in different risk groups, in both urban and rural environments. There are research gaps on 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 to women and their role in climate change adaptation need to be investigated (Mula *et al.*, 2010). There is also a need to identify low cost options and a need for scaling up of the same, considering the vast majority of population living below the poverty line in some of the least developed countries. Greater understanding is required on linkages between local livelihoods, ecosystem functions, and land resources for creating positive impact on local livelihoods and poverty reduction in areas with greater dependency on natural resources (Paul *et al.*, 2009). 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 is needed on climate change impacts, vulnerability and adaptation on urban settlements, especially cities with population under 500,000, sharing about half of region's urban population. While urban areas account for over 80% of region's GDP, detailed estimates on impact of climate change on various sectors of urban economy, including tourism industry needs priority. Research priority for promoting adaptation polices at municipal level should be given emphasis. It is assumed that the existing policies should be expanded into adaptation; however the implementation of adaptation measures is still in its infancy. In order to promote adaptation policies at municipal level, two types of research should be highly prioritized. The first is on research regarding quantitative assessment of impacts and adaptation of climate change, which would also include different target years, different stabilized purposes, multiple GCM results, and social economic scenarios. This would be useful in determining specific target periods and quantitative countermeasure levels, while taking account of the progress of future global warming. In this process, uncertainty should be noted in correspondence to climate change scenarios and assessment techniques. The second type of research should be action oriented, focusing on implementing adaptation policy, taking into account necessary cost and socio-economic innovation. In assessing the quantitative effects of an adaptation policy, especially in Asia, researches utilizing various social-economic scenarios are significant to more accurately reflect on diversities in a social system, life style, culture, and climate.

Climate change will not have uniform impact on a population within a country but rather depends on location, socio-economic conditions and level of preparedness (Begum et al, 2011). Negative impacts on agriculture productivity would have significant impact 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 limted considering the vast majority of population living below 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 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 Himalayan region (Xu *et al.*, 2009).

While mitigation efforts are essential, 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 mitigation policies, most cost-effective mitigation measures within sector and across sectors would be the key information needed to devise these policies (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 Issues – Mekong River Basin Case Study

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) [see Figure 24-3]. 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 are involved in fishing to sustain their livelihoods; fishing is particularly important for rural households in the LMB (Hortle, 2009; Mainuddin et al., 2011b). Although there is no precise data on fishery exports originating in the LMB, the exports of fishery products from the four riparian countries in total reached US$5.6 billion in 2008 (FAOSTAT, 2008; Mainuddin et al., 2011b).

[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, 2010): increase in temperature (for all riparian countries), changes in rainfall patterns (e.g. Thailand and Vietnam), intensification of flooding and droughts (e.g. Laos) and sea level rise (e.g. Vietnam's Mekong Delta). Agricultural output has been noticably impacted by these climate related events, for example resulting in rice production loss in Cambodia and Laos (1995 – 2001). Negative impacts on capture fisheries in the LMB as a result of climate change as well as dam construction are observed (MRC, 2010; Hortle, 2009; Wyatt and Baird, 2007).

National level climate change adaptation plans have been formulated in all four riparian countries. A commonly shared scientific forecast on possible future climate impacts as well as an integrated and co-ordinated 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): increase in temperature, wet season rainfall, flooding frequency and duration along the Mekong River; decrease in dry season rainfall; sea level rise and salinity intrusion in the Mekong delta.

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

1. Reduced agricultural output and yields, particularly for rice (MRC, 2009)
2. Loss of fertile land and population displacement in the Mekong river delta (MRC, 2009; MRC, 2010)
3. Reduced fish survival, growth and reproductive success (UNEP, 2010)

To address these vulnerabilities, *adaptation needs* are primarily in areas of improved water management, farming and fishing practices as well as coastal protection (Johnson et al., 2010; Hoanh et al., 2003). *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 co-ordination 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 an 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 co-ordination 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).

Currently sub-optimal resource allocation and adaptation gaps for some sectors or geographies in the LMB most likely exist. A common *framework* of what constitutes 'successful' adaptation initiatives and a holistic transboundary climate change adaptation management framework in the LMB context *does not exist* to date and is currently subject of an ongoing study.

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 SE 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 SE 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).

SE 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. Climate change projections suggest that many peatland areas in SE Asia will experience reduced rainfall and increased seasonality over the coming decades (IPCC, 2007), leading 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 Issik Kul Lakes, and Ob and Tarim rivers (Aizen *et al.*, 1995; 1998). All rivers, except the Ob 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. In the last 50 years (1960-2009), central Asian glaciers lost on average 10% of their area and 15% of their ice volume.

The rate of glacier area change varies. Accelerated glacier ice melt increases total river runoff in heavy glacierized basins by 8% (Aizen and Aizen, 2012a). 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 Table 24-12 and Figure 24-4). Altai-Sayan glaciers lost 14% area on average. 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 (Surazakov *et al.*, 2007; Shahgedanova *et al.*, 2010; Aizen *et al.*, 2012b). 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 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.*, 2012c). The Fedchenko Glacier in central Pamir, which is the world's largest alpine glacier outside of the Polar regions (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 Issik Kul lakes, and the Sir Darýa 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 (20 mm) 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 Pamir glaciers have been revealed as more stable glaciers to climate changes in central Asia (Aizen and Aizen, 2012a; Bamber, 2012; Jacob, *et al*., 2012). 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 and Aizen, 2012d).

[INSERT TABLE 24-12 HERE
Table 24-12: Location and major characteristics of central Asia glaciations.]

[INSERT FIGURE 24-4 HERE
Figure 24-4: The difference in losses of glacier area in Altai-Sayan, Pamir and Tien Shan determined by location of the mountain ridges in relation to major atmospheric moisture flow and by elevation above sea-level. 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; Mitchel *et al.,* 2004). Then, the area covered by central Asian glaciers may shrink by 40% and the glacier volume by 60% of the current state. The IPCC scenarios predict, on average, an increase in summer air temperature of 2ºC to 8ºC (about 4ºC) and an increase in magnitude of precipitation of 0.84-1.24 (about 1.1 times) (Mitchel *et al.,* 2004). 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 (Aizen *et al.*, 2007). During the last 12,000 years, the warmest period was in the Holocene Climatic Optimum (Thermal Maximum, circa 7,500-7,600BP), when mean air temperature was 4.2ºC higher than modern, i.e. the annual average temperature in the last three decades. Nevertheless, central Asian glaciers were able to survive during the Thermal Maximum. Thus, for complete glacier disappearance mean air temperature should be at least 5ºC higher than modern (Aizen *et al.,* 2012e).

24.9.4. Is the Aral Sea Dying?

The Aral Sea (see Figure 24-5) was a very large sea (lake) in Central Asia that was number four (in area) in the list of the world's lakes before the 1960s (Letolle, 2008; Kostianoy and Kosarev, 2010). It is located in the Karakum and Kyzylkum deserts. Navigation and the fishery (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 18 August 2008 from MODIS-Terra. 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 irrationally used in order to increase irrigation of agricultural lands as well as to create artificial water reservoirs (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; Glantz, 1999; Micklin and Williams, 1996). For the last fifty years we have been observing a progressive desiccation of the Aral Sea and deterioration of its environment. 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. The Aral Sea related economic spheres lost their importance. The consequences of the sea degradation represent a big threat to the quickly growing population in the Priaralie (from 14 million people in 1960 to 45 million people 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 atmospheric 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 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 of the mean annual air temperature in the Aral region in 1960–2000 was 1^{o}C (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 of the sea 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 dry seasons. The western part of the Large Aral Sea, being a relatively narrow and deep lake, may slowly die in the absence of external water supply (Kostianoy and Kosarev, 2010; Micklin, 2010; Breckle *et al.*, 2012; Kostianoy, 2012).

Frequently Asked Questions

FAQ 24.1: Since AR4, what is new in our knowledge about the changing climate in Asia?

The observed increasing trend of annual mean temperature of between less than 1°C to 3°C per century and warming in daily temperature extremes has been confirmed in many countries of Asia. The warming trend is projected to continue during the 21st century across the region irrespective of stabilization scenarios. Observed trends of annual and heavy precipitation are varied throughout Asia. Variability of trends in average and extreme precipitation is projected to be wider within the region.

FAQ 24.2: How will the projected impact of climate change on freshwater resources by the 2050s affect natural ecosystems and society?

Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources positively in the near future but negatively in the long term perspective. Changes in river flow will impact natural habitats and species that are sensitive to flow extremes. Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease due to climate change. Water scarcity is expected to be a big challenge in these regions. Population growth and increasing demand arising from higher standards of living, could adversely affect more than 1 billion people. Better water management strategies are needed to ease water scarcity. Water saving technologies and changing of crops into drought tolerant crops are found to be successful adaptation options in the region.

FAQ 24.3: How will climate change affect food production and food security in Asia?

Climate change impacts on crop production would be generally negative in many regions. For rice, most models show that higher temperatures will lead to lower rice yields as a result of shorter growing period. However, with CO_2 fertilization effect, rice yield could increase with climate change. This is also generally true for other crops. The impacts of climate change on food production and food security will vary within regions and countries- increasing yields for some areas (eg. cereal production in north and east Kazakhstan) and declining yields in others (eg. wheat in the Indo-Gangetic Plain of South Asia). There are many potential adaptation strategies such as crop breeding but research on their effectiveness is limited.

FAQ 24.4: Who are the people most at risk in Asia from climate change?

People living in low lying coastal zones and flood plains are most at risk from climate extremes and disasters in Asia. 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. More frequent and intense heat-waves in Asia will increase mortality and morbidity in vulnerable groups, particularly in urban environments. Urban population growth will lead to urban land-use and land-cover changes and in turn will have considerable impacts on climate.

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. Cross-sector collaborations are required to develop adaptive measures, involving the health sector and disaster preparedness programs, water management, sanitation, urban planning, food industry and the animal health sector.

FAQ 24.6: What are the challenges in climate impacts, vulnerabilities and adaptation research in Asia?

Gaps in data are a major challenge for Asia. 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.

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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 • China, Macao Special Administrative Region • Japan	• North Korea • People's Republic of China • South Korea • Taiwan Province of China
North Asia (2)	• Mongolia	• Russia (East of Ural)
South Asia (8)	• Afghanistan • Bangladesh • Bhutan • India	• Maldives • Nepal • Pakistan • Sri Lanka
South East 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 climate trends and variability.

Region	Countries	Parameter	Unit	Change	Base year	Period	Reference
North Asia (2)	Mongolia	AMT	°C	+2.14	N/A	1940-2005	Dagvadorj et al., 2009
		AMP	mm/y	-0.1 ~ -2.0	N/A	1940-2005	Dagvadorj et al., 2009
	*NW Khentey	AMT	°C	+2.5	N/A	1961-2007	Dulamsuren et al., 2010
	*SW Khentey	AMT	°C	+4.4	N/A	1950-2007	Dulamsuren et al., 2010
	*SW Khentey (winter)	AMT	°C	+7.1	N/A	1950-2007	Dulamsuren et al., 2010
	*E Khengay	AMT	°C	+1.8	N/A	1937-2007	Dulamsuren et al., 2010
	*SE Khentey	AMT	°C	+1.2	N/A	1942-2007	Dulamsuren et al., 2010
	*NW Khentey	AMP	mm	-100	N/A	1961-2007	Dulamsuren et al., 2010
	*SW Khentey	AMP	mm	+15	N/A	1950-2007	Dulamsuren et al., 2010
	*E Khengay	AMP	mm	-20	N/A	1937-2007	Dulamsuren et al., 2010
	*SE Khentey	AMP	mm	+50	N/A	1942-2007	Dulamsuren et al., 2010
	Russia	AMT	°C	+1.29	1961-1990	1907-2006	Anisimov et al., 2008
		AMT	°C	+1.33	1961-1990	1976-2006	Anisimov et al., 2008
		AMP	mm/10y	+7.2	1961-1990	1976-2006	Anisimov et al., 2008
East Asia (7)	China, Hong Kong Special Administrative Region	AMT	°C/10y	+0.12	N/A	1885-2008	Ginn et al., 2010
		AMT	°C/10y	+0.16	N/A	1947-2008	Ginn et al., 2010
		AMT	°C/10y	+0.27	N/A	1979-2008	Ginn et al., 2010
		$T_{min.}$	°C/10y	+0.27	N/A	1947-2008	Ginn et al., 2010
		AMP	mm/10y	+25	N/A	1885-2008	Ginn et al., 2010
		AMP	mm/10y	not significant		1947-2008	Ginn et al., 2010
	Japan	AMT	°C/100y	+1.15	1971-2000	1898-2010	JMA, 2011
		AMP	No clear trend				MEXT et al., 2009
	*Tokyo	AMT	°C	+2.93 (+0.24/10y)	N/A	1876-2000	Schaefer and Domroes, 2009
	*Tokyo	AMT	°C	+2.95 (+0.30/10y)	N/A	1901-2000	Schaefer and Domroes, 2009
	*Hakodate	AMT	°C	+0.35 (+0.04/10y)	N/A	1901-2000	Schaefer and Domroes, 2009
	*Okayama	AMT	°C	+2.14 (+0.44°C/10y)	N/A	1951-2000	Schaefer and Domroes, 2009
	*Hiroshima	AMT	°C	+2.35 (+0.98/10y)	N/A	1976-2000	Schaefer and Domroes, 2009
	*North Japan (March/April)	AMT	°C/y	+0.047 ~ +0.0771	N/A	1977-2004	Fujisawa and Kobayashi, 2010
	People's Republic of China	AMT	°C/10y	0.09±0.017	1971-2000	1900-2006	Li et al., 2010
		AMT	°C/10y	0.26±0.032	1971-2000	1954-2006	Li et al., 2010
		AMT	°C/10y	0.45±0.13	1971-2000	1979-2006	Li et al., 2010
		AMT	°C/10y	+0.22	N/A	1951-2001	Ren et al., 2005
		AMT	°C/10y	+0.36	N/A	1951-2001	Ren et al., 2008
	*North China	AMT	°C	+1.16 (+0.29/10y)	N/A	1961-2000	Ren et al., 2008
	*North China	AMT	°C/10y	+0.18 (adjusted UHI)	N/A	1961-2000	Ren et al., 2008
	*North China (winter)	AMT	°C	+2.48 (+0.62/10y)	N/A	1961-2000	Ren et al., 2008
	*North China (winter)	AMT	°C/10y	+0.5 (adjusted UHI)		1961-2000	Ren et al., 2008
	South Korea	AMT	°C	+1.87	1971-2000	1908-2008	Kim et al., 2010
		AMT	°C	+1.37	1971-2000	1954-2008	Kim et al., 2010
		AMT	°C	+1.44	1971-2000	1969-2008	Kim et al., 2010
		AMP	%	+5.6	1973-1980	2001-2008	Kim et al., 2010
	Taiwan Province of China	AMT	°C/10y	+0.14	1980-1999	1911-2009	Hsu et al., 2011
		AMT	°C/10y	+0.19	1980-1999	1959-2009	Hsu et al., 2011
		AMT	°C/10y	+0.29	1980-1999	1979-2009	Hsu et al., 2011
		DP≧0.1mm	days/10y	-4.1	1980-1999	1911-2009	Hsu et al., 2011
		DP≧0.1mm	days/10y	-5.2	1980-1999	1959-2009	Hsu et al., 2011
		DP≧0.1mm	days/10y	-6.26	1980-1999	1979-2009	Hsu et al., 2011
South East Asia (12)	Indonesia *Brontas Catchment	MMP	mm/m	-0.12 ~ -2.12	N/A	1955-2005	Aldrian and Djamil, 2008
	*Brontas Catchment	AMP	mm/y	-1.23 ~ -24.25	N/A	1955-2005	Aldrian and Djamil, 2008
	The Philippines	AMT	°C	+0.648	1971-2000	1951-2010	PAGASA, 2011
		AMT	°C/y	+0.0108	1971-2000	1951-2010	PAGASA, 2011
		$T_{max.}$	°C	+0.36	1971-2000	1951-2010	PAGASA, 2011
		$T_{min.}$	°C	+1	1971-2000	1951-2010	PAGASA, 2011

Region	Countries	Parameter	Unit	Change	Base year	Period	Reference
South Asia (8)	Afghanistan	AMT	°C	+0.6	N/A	1960-2008	Savage et al., 2009
		AMT	°C/10y	+0.13	N/A	1960-2008	Savage et al., 2009
		AMP	mm/m	-0.5	N/A	1960-2008	Savage et al., 2009
		AMP	%/10y	-2	N/A	1960-2008	Savage et al., 2009
	Bangladesh	AMT	°C/10y	+0.097	N/A	1958-2007	Shahid, 2010
		AMP	mm/y	+5.53	N/A	1958-2007	Shahid, 2010
	*Western Bangladesh	AMP	mm/y	+6.97 ~ +7.79	N/A	1958-2007	Shahid, 2010
	*Northern Bangladesh	AMP	mm/y	+14.39 ~ +16.45	N/A	1958-2007	Shahid, 2010
	India	AMT	°C	+0.56	1961-1990	1901-2009	Attri and Tyagi, 2010
		$T_{max.}$	°C	+1.02	1961-1990	1901-2009	Attri and Tyagi, 2010
		$T_{min.}$	°C	+0.12	1961-1990	1901-2009	Attri and Tyagi, 2010
		AMP	No significant national trend.			1901-2009	Attri and Tyagi, 2010
		AMT	°C/100y	+0.68	N/A	1880-2000	Lal, 2003
		AMT	C/y	+0.0056°	N/A	1948-2008	Ganguly, 2011
	Nepal	AMT	°C/y	+0.06	N/A	1977-1994	Shrestha et al., 1999
	Pakistan	AMT	°C	+0.57	1961-1990	1901-2000	Chaudhry et al., 2009
		AMT	°C/10y	+0.099	1961-2000	1960-2007	Chaudhry et al., 2009
		AMT	°C	+0.47±0.21	1961-2000	1960-2007	Chaudhry et al., 2009
		$T_{max.}$	°C/10y	+0.18	N/A	1960-2007	Chaudhry et al., 2009
		$T_{max.}$	°C	+0.87±0.26	N/A	1960-2007	Chaudhry et al., 2009
		$T_{min.}$	°C/10y	+0.1	N/A	1960-2007	Chaudhry et al., 2009
		$T_{min.}$	°C	+0.48±0.2	N/A	1960-2007	Chaudhry et al., 2009
		AMP	mm	+61	N/A	1901-2007	Chaudhry et al., 2009
		AMP	mm	-156	N/A	1901-1954	Chaudhry et al., 2009
		AMP	mm	+35	N/A	1955-2007	Chaudhry et al., 2009
	*Karachi	AMT	°C	+2.25 (+0.38/10y)	N/A	1947-2005	Sajjad et al., 2009
	*Upper Indus River basin	AMT	°C	+1.79	N/A	1967-2005	Khattak et al., 2011
	*Middle Indus River basin	AMT	°C	+1.66	N/A	1967-2005	Khattak et al., 2011
	*Lower Indus River basin	AMT	°C	+1.20	N/A	1967-2005	Khattak et al., 2011
	Sri Lanka	AMT	°C/y	+0.005 ~ +0.035	N/A	1961-2000	Iqbal, 2010
		AMP	mm/y	-1.55 ~ -19.06	N/A	1961-2000	Iqbal, 2010
		AMT	°C/10y	+0.3 ~ +0.93	N/A	1869-2007	De Costa, 2008
		AMT	°C/10y	+0.75 ~ +0.94	N/A	1910-2007	De Costa, 2008
	*Four of 7 study areas	AMP	mm/y	-0.28 ~ -0.84	N/A	1869-2007	De Costa, 2008
West Asia (17)	Armenia	AMT	°C	+0.85	1961-1990	1935-2007	Gabrielyan et al., 2010
		AMP	%	-6	1961-1990	1935-2007	Gabrielyan et al., 2010
Central Asia (5)	*General	AMT	°C	+1 ~ +2	N/A	1880-2000	Lioubimtseva et al., 2005
	Kazakhstan	AMT	°C/10y	+0.31	N/A	1936-2005	Kryukova et al., 2009
		AMP	No definite national trend.			1936-2005	Kryukova et al., 2009
	Kyrgyzstan	AMT	°C	+1.6	N/A	1901-2000	Iliasov et al., 2003
		AMP	mm	+23mm (+6%)	N/A	1901-2000	Iliasov et al., 2003
	Tajikistan *plain region	AMT	°C/10y	+0.1 ~ +0.2	N/A	1940-2005	Karimov et al., 2008
	*mountainos region	AMT	°C	+0.3 ~ +0.5	N/A	1940-2005	Karimov et al., 2008
	*up to 2500 masl	AMP	%	+8 (insignificant)	N/A	1940-2005	Karimov et al., 2008
	*mountainous areas	AMP	%	-3 (insignificant)	N/A	1940-2005	Karimov et al., 2008
	Turkmenistan	AMT	°C/10y	+0.18	N/A	1931-1995	MNPT, 2000
		AMP	mm/10y	+12	N/A	1931-1995	MNPT, 2000
	Uzbekistan	$T_{max.}$	°C/10y	+0.22	N/A	1951-2008	Uzhydromet, 2008
		$T_{min.}$	°C/10y	-0.36	N/A	1951-2008	Uzhydromet, 2008
Tibetan Plateau		AMT	°C	+1.8 (0.36/10y)	N/A	1961-2007	Wang et al., 2008
		AMT	°C/10y	+0.447	N/A	1962-2001	Xu et al., 2008
		AMP	mm/y	+0.614	N/A	1961-2001	Xu et al., 2008

Table 24-3: Summary of observed changes in extreme events and severe climate anomalies.

Region	Countries	Key trend	Period	Reference
Temperature Extremes				
North Asia	*SREX	*Likely* increases in warm days/nights and *likely* decreases in cold days/nights		SREX, Ch.3, Table 3.2
		Spatially varying trends in warm spells, overall increase in warm spell duration index (WSDI);WSDI decrease in some areas		SREX, Ch.3, Table 3.2
	Mongolia	Decrease in warm day-times and nights	1948-2006	Fang et al., 2008
	Russia	Increase in warm daytimes and nights in northeastern Siberia	1948-2006	Fang et al., 2008
East Asia	*SREX	*Likely* increases in warm days and *likely* decreases in cold days		SREX, Ch.3, Table 3.2
		Decreases in cold nights and increases in warm nights		SREX, Ch.3, Table 3.2
		Increase in warm season heat waves in China		SREX, Ch.3, Table 3.2
		Increase in WSDI in North China, but decline in South China		SREX, Ch.3, Table 3.2
	People's Republic of China	Increasing frequency and severity of regional wet heatwaves events with a magnitude of 0.29 times per decade	1960-2008	Ding and Qian, 2011
		Extreme warm-month events have strong spatial dependance, with smaller variability over the Tibetan Plateau, North China plain and coastal areas of South China, and larger variability over North China	1960-2007	Wan, 2009
		Significant decrease in warm daytimes and nights in North China	1948-2006	Fang et al., 2008
	South Korea	20 heatwaves with mean annual duration of 9.3 days (longest being 33 days); Mean relative excess total mortality shows a positive trend of +5.9%; Cardiovascular disease mortality shows a positive trend of +9%	1991-2005	Kysely and Kim, 2009
S-E Asia	*SREX	Increases in warm days, decreases in cold nights		SREX, Ch.3, Table 3.2
		Decreases in cold days, increases in warm nights in the northern part of domain		SREX, Ch.3, Table 3.2
	*General	Significant increase in warm day-times and nights in inland and on the coast	1948-2006	Fang et al., 2008
	Malaysia	Significant increase in warm nights	1948-2006	Fang et al., 2008
South Asia	*SREX	Increase in warm days/nights and decrease in cold days/nights		SREX, Ch.3, Table 3.2
	*General	Increase in warm daytimes and nights	1948-2006	Fang et al., 2008
	Afghanistan	Decrease in warm daytimes	1948-2006	Fang et al., 2008
	Pakistan	Decrease in warm daytimes	1948-2006	Fang et al., 2008
West Asia	*SREX	*More likely than not* decrease in cold days and a *very likely* increase in warm days		SREX, Ch.3, Table 3.2
		Likely decrease in cold nights and *likely* increase in warm nights		SREX, Ch.3, Table 3.2
		WSDI increase		SREX, Ch.3, Table 3.2
	*General	Increase in warm daytimes and nights	1948-2006	Fang et al., 2008
Central Asia	*SREX	*Likely* increases in warm days/nights and *likely* decreases in cold days/nights		SREX, Ch.3, Table 3.2

Region	Countries	Key trend	Period	Reference
Heavy precipitation				
North Asia	*SREX	Increase in some regions, but spatial variations		SREX, Ch.3, Table 3.2
		Some increase western Russia, especially in winter	1950-2000	SREX, Ch.3, Table 3.2
	Russia	-4 to +4 days in absolute terms, or -40% to +40% in relative terms	1936-2000	Bogdanova et al., 2010
		In the western part, areas that show increase considerably exceed areas of decrease		
		In the eastern part, speed of the increase is lower, and the speed of decrease is higher than in the western part		
East Asia	*SREX	Spatially varying trends in heavy precipitation		
	Japan	+2.49%/decade for ≥100mm precipitation days	1901-2004	Fujibe et al., 2006
		Increased heavy precipitation mainly in West Japan and in autumn, although weak positive trends are found in most other regions and seasons		
		Trend in annual maximum number of heavy daily precipitation indices is +0.89%/decade for whole territory of Japan		
		+4.2%/decade for ≥200mm/day +2.4%/decade for ≥100mm/day -0.9%/decade to -1.5%/decade for ≥1mm/day	1901-2006	Fujibe, 2008
		+63.2%±52.2%/decade for ≥300mm/6h +37.6%±30.4%/decade for ≥200mm/6h +48.4%±45%/decade for ≥100mm/h	1979-2007	
	People's Republic of China	Increases in >50mm/day, and/or heavy (25-50mm/day) precipitation in SE China	1978-2002	Yao et al., 2008;
		Sudden increase in severe floods in Poyang Lake	during past few decades	Shankman et al., 2006
		All of the severest floods since 1950 occurred during or immediately following El Niño events	since 1950	
	South Korea	A gradual increase in heavy summer precipitation days (≥30mm/day) around mid-late 1970s	1954-2001	Ho et al., 2003
		Significant increasing trends for indices measuring heavy precipitation frequency and intensity	1971-2000	Im et al., 2008
		Pronounced enhancement of the number of days with precipitation above 80mm intensity, percentage of total rainfall from events above longterm 95th perceltile, and greatest 10-day total precipitation in southern parts		Im et al., 2011
S-E Asia	*SREX	Spatially varying trends in heavy precipitation		
	Malaysia	Decreasing trend in frequency of daily rainfall exceeding the 1971-2005 mean 99th percentile (days) at 60% of stations	1971-2005	Zin et al., 2010
		Increasing trends in wet day intensities greater or equal to 95th and 99th percentile are +5.08mm/decade and +8.75mm/decade respectively (Petaling Java)		
		Increasing trends in wet day intensities greater or equal to 95th and 99th percentile are +3.41mm/decade and +5.57mm/decade respectively (Subang)		
South Asia	*SREX	Mixed signal in India		
	India	+6%/decade for ≥150mm/day	1901-2004	Rajeevan et al., 2008
		+14.5%/decade for ≥150mm/day	1951-2004	
		+10%/decade for ≥100mm/day	1951-2000	Goswami et al., 2006
West Asia	*SREX	Decrease in heavy precipitation events		
Central Asia	*SREX	Spatially varying trends in heavy precipitation		
Tropical Cyclones				
East Asia	*General	Increasing typhoon influence in subtropical East Asia and considerable decrease over South China Sea due to changes in large-scale steering flow (tropospheric cooling in the last 20 years was suggested as cause)	1965-2003	Wu et al., 2005
	People's Republic of China	Tropical cyclone frequency shows a decreasing trend over most part of China except at some locations (low reaches of Yangtze River) where averaged number of tropical cyclones over last 25 years decreased about 1-2 per year, relative to first 25 years	1955-2007	Ying et al., 2011
S-E Asia	*General	Growing duration of the most extreme winds (tropical storms and typhoons) over South East Asian seas, mainly the South China Sea and the Philippine Sea	1960-2000	Rozynski et al, 2009
*East China Sea and Philippine Sea		Significant decrease in frequency of typhoon passage in East China Sea and Philippine Sea in the 1980-2001 period, relative to 1951-1979	1951-2001	Ho et al., 2004
		A continuous downward trend over Philippine Sea is found at a rate of change of -0.6%/year, which amounted to 45% decrease over the study period		
Pacific		Decreasing trend in tropical cyclone number in northwestern Pacific	1959-2006	Chen, 2009
		Trend of tropical cyclone frequency in southeastern Pacific shows an increase until early 1990s and then a moderate decrease		

Table 24-4: Summary of projected changes for a variety of climate parameters.

Region	Countries	Paramete	Unit	Projected change	Scenario	GCM	RCM	Base year	Period	Reference
Asia		AMT	°C	+1.7±0.6 (1.0,2.8)	RCP2.6			1986-2005	2081-2100	WGI AR5
		AMT	°C	+2.8±0.8 (1.8,4.0)	RCP4.5			1986-2005	2081-2100	WGI AR5
		AMT	°C	+3.5±0.9 (2.3,4.9)	RCP6.0			1986-2005	2081-2100	WGI AR5
		AMT	°C	+5.6±1.3 (3.7,7.8)	RCP8.5			1986-2005	2081-2100	WGI AR5
		AMT	°C	large increases	SRES A2	MRI-CGCM2.2	CRIEPI-RegCM3	1981-1990	2046-2055	Takayabu et al., 2007
		AMT	°C	large increases	SRES A2	MRI-CGCM2.2	MRI-RCM	1981-1990	2046-2055	Takayabu et al., 2007
North Asia (2)	*General	AMP	%	+15 ~ +25	SRES A1B	*1		1981-2000	2081-2100	Kim and Byun, 2009
	Mongolia	AMP	mm/y	increase	SRES A2	MRI-CGCM2.2	CRIEPI-RegCM3	1979-2005	2046-2055	Takayabu et al., 2007
		AMP	mm/y	increase	SRES A2	MRI-CGCM2.2	MRI-RCM	1979-2005	2046-2055	Takayabu et al., 2007
	*intensity of warming in summer season is higher than winter	AMT	°C	+1	SRES A2	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMT	°C	+2.7	SRES A2	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
		AMT	°C	+5	SRES A2	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
		AMT	°C	+0.9	SRES A1B	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMT	°C	+3	SRES A1B	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
	**increase in summer precipitation will be smaller than winter precipitation	AMT	°C	+4.6	SRES A1B	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
		AMT	°C	+0.8	SRES B1	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMT	°C	+2.1	SRES B1	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
		AMT	°C	+3.1	SRES B1	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
		AMP	%	+2	SRES A2	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMP	%	+9	SRES A2	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
		AMP	%	+15	SRES A2	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
		AMP	%	0	SRES A1B	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMP	%	+7	SRES A1B	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
		AMP	%	+16	SRES A1B	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
		AMP	%	+3	SRES B1	HadCM3		1980-1999	2011-2030	Dagvadorj et al., 2009
		AMP	%	+6	SRES B1	HadCM3		1980-1999	2046-2065	Dagvadorj et al., 2009
		AMP	%	+11	SRES B1	HadCM3		1980-1999	2080-2099	Dagvadorj et al., 2009
East Asia (7)	*General	AMP	%	+5 ~ +15	SRES A1B	*1		1981-2000	2081-2100	Kim and Byun, 2009
	China, Hong Kong Special Administrative Region	AMT	°C	+3	"low-end"			1980-1999	2090-2099	Ginn et al., 2010
		AMT	°C	+6.8	"high-end"			1980-1999	2090-2099	Ginn et al., 2010
		AMT	°C	+4.8	"middle-of-the-road"			1980-1999	2090-2099	Ginn et al., 2010
		AMP	%	+11	above three			1980-1999	2090-2099	Ginn et al., 2010
	People's Republic of China	AMP	mm/y	increase in N. China	SRES A2	MRI-CGCM2.2	CRIEPI-RegCM3	1979-2005	2046-2055	Takayabu et al., 2007
		AMP	mm/y	increase in N. China	SRES A2	MRI-CGCM2.2	MRI-RCM	1979-2005	2046-2055	Takayabu et al., 2007
		$HW_{freq.}$	times/y	increase (max. >5)	SRES A2	HadAM3P/HadCM3	PRECIS	1961-1990	2071-2100	Yang et al., 2010
		$HW_{dur.}$	days	7 to 14 (mostly 9)	SRES A2	HadAM3P/HadCM3	PRECIS	1961-1990	2071-2100	Yang et al., 2010
		AMT	°C	+3.5(RCM)~+3.7(GCM)	SRES A2	FvGCM/CCM3	ICTP RegCM3	1961-1990	2071-2100	Gao et al., 2011
		AMP	%	+5.5(RCM)~+11.3(GCM)	SRES A2	FvGCM/CCM3	ICTP RegCM3	1961-1990	2071-2100	Gao et al., 2011
	South Korea	$T_{max.}$	°C	33.2	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
		$T_{min.}$	°C	-6.6	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
		FD	days	65.3	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
		HD	days	47.2	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
		$HW_{dur.}$	days	14	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
		$DRY_{max.}$	days	20	SRES A1B	ECHAM5/MPI-OM	RegCM3	1971-2000	2001-2100	Im et al., 2011
	Taiwan, Province of China	AMT	°C	+1.7 ~ +3.4	SRES A1B	XX [in Chinese]		1980-1999	2080-2099	Hsu et al., 2011
		AMP	%	-3 ~ -22	SRES A1B	XX [in Chinese]		1980-1999	2080-2099	Hsu et al., 2011
South East Asia (12)	*General	$AMT_{max.}$	°C	+0.5 ~ +1.5	SRES A1B	ECHAM5/MPI-OM	WRF	1990-1999	2045-2054	Chotamonsak et al., 2011
		$AMT_{min.}$	°C	+0.81 ~ +1.52	SRES A1B	ECHAM5/MPI-OM	WRF	1990-1999	2045-2054	Chotamonsak et al., 2011
		RSLR	m	+0.03	SRES A2	*DIVA, IMAGE2.2, CLIMBER-2		1995	2010	McLeod et al., 2010
		RSLR	m	+0.08 ~ +0.09	SRES A2			1995	2030	McLeod et al., 2010
		RSLR	m	+0.16 ~ +0.17	SRES A2			1995	2050	McLeod et al., 2010
		RSLR	m	+0.43 ~ +0.46	SRES A2			1995	2100	McLeod et al., 2010
		RSLR	m	+0.03	SRES B1			1995	2010	McLeod et al., 2010
		RSLR	m	+0.08 ~ +0.09	SRES B1			1995	2030	McLeod et al., 2010
		RSLR	m	+0.14 ~ +0.15	SRES B1			1995	2050	McLeod et al., 2010
		RSLR	m	+0.30 ~ +0.32	SRES B1			1995	2100	McLeod et al., 2010
	The Philippines	AMT	°C	+0.7	SRES A2	ECHAM4	PRECIS	1971-2000	2006-2035	PAGASA, 2011
		AMT	°C	+1	SRES A1B	HadCM3Q0	PRECIS	1971-2000	2006-2035	PAGASA, 2011
		AMT	°C	+0.7	SRES B2	ECHAM4	PRECIS	1971-2000	2006-2035	PAGASA, 2011
		AMT	°C	+1.7	SRES A2	ECHAM4	PRECIS	1971-2000	2036-2065	PAGASA, 2011
		AMT	°C	+2	SRES A1B	HadCM3Q0	PRECIS	1971-2000	2036-2065	PAGASA, 2011
		AMT	°C	+1.6	SRES B2	ECHAM4	PRECIS	1971-2000	2036-2065	PAGASA, 2011
		AMT	°C	+3.4	SRES A2	ECHAM4	PRECIS	1971-2000	2036-2065	PAGASA, 2011
		AMT	°C	+3.1	SRES A1B	HadCM3Q0	PRECIS	1971-2000	2036-2065	PAGASA, 2011
		AMT	°C	+2.5	SRES B2	ECHAM4	PRECIS	1971-2000	2036-2065	PAGASA, 2011
	Thailand *Ping River Basin	AMT	°C	+0.4 ~ +0.5	SRES A2	ECHAM4/OPYC3		1990-1999	2020s	Sharma et al., 2007
		AMT	°C	+1.3 ~ +1.5	SRES A2	ECHAM4/OPYC3		1990-1999	2050s	Sharma et al., 2007
		AMT	°C	+0.3 ~ +0.4	SRES B2	ECHAM4/OPYC3		1990-1999	2020s	Sharma et al., 2007
		AMT	°C	+0.9 ~ +1.1	SRES B2	ECHAM4/OPYC3		1990-1999	2050s	Sharma et al., 2007
	Timor-leste	AMT	°C	+0.8 (+0.4 ~ +1.5)	SRES A1B,A2, B1	*2		1961-1990	2020s	Cardno Acil and KWK Consulting, 2010; Kirono 2010
		AMT	°C	+1.5 (+0.7 ~ +2.8)	SRES A1B,A2, B1	*2		1961-1990	2050s	
		AMT	°C	+2.2 (+0.8 ~ +4)	SRES A1B,A2, B1	*2		1961-1990	2080s	
		AMP	%	+2 (-12 ~ +15)	SRES A1B,A2, B1	*2		1961-1990	2020s	
		AMP	%	+4 (-25 ~ +15)	SRES A1B,A2, B1	*2		1961-1990	2050s	
		AMP	%	+6 (-21 ~ +32)	SRES A1B,A2, B1	*2		1961-1990	2080s	
		HWDI	days	+2		CSIRO-CCAM		1981-2000	2041-2060	Kirono, 2010
South Asia (8)	*General	AMP	%	+5 ~ +10	SRES A1B	*1		1981-2000	2081-2100	Kim and Byun, 2009
	Afghanistan	AMT	°C	+1.4	SRES A1, A2, B1	15 GCM ensemble		1970-1999	2020	Savage et al., 2009
		AMT	°C	+2.8 ~ +5	SRES A1, A2, B1	15 GCM ensemble		1970-1999	2090	Savage et al., 2009
		AMP	mm	+10 ~ +20	SRES A1, A2, B1	15 GCM ensemble		1970-1999	2030s	Savage et al., 2009
		AMP	mm	-10 ~ -40	SRES A1, A2, B1	15 GCM ensemble		1970-1999	2090s	Savage et al., 2009
	Pakistan	AMT	°C/10y	+1.73	SRES A2	17-model ensemble	NCC-RCM		2011-2050	Chaudhry et al., 2009
		AMT	°C/10y	+1.26	SRES A1B	17-model ensemble	NCC-RCM		2011-2050	Chaudhry et al., 2009
		AMT	°C/10y	-0.89	SRES B1	ECHAM-5	NCC-RCM		2011-2050	Chaudhry et al., 2009
		AMP	mm/10y	+0.51	SRES A2	17-model ensemble	NCC-RCM		2011-2050	Chaudhry et al., 2009
		AMP	mm/10y	+0.41	SRES A1B	17-model ensemble	NCC-RCM		2011-2050	Chaudhry et al., 2009
		AMP	mm/10y	+0.24	SRES B1	ECHAM-5	NCC-RCM		2011-2050	Chaudhry et al., 2009

Region	Countries	Paramete	Unit	Projected change	Scenario	GCM	RCM	Base year	Period	Reference
West Asia (18)	*General	AMT	°K	+1.41±0.32	SRES A2	*3		2000-2009	2045-2054	Evans, 2009
		AMT	°K	+3.95±0.73	SRES A2	*3		2000-2009	2090-2099	Evans, 2009
		AMP	mm	-8.42±16.08	SRES A2	*3		2000-2009	2045-2054	Evans, 2009
		AMP	mm	-25.45±28.66	SRES A2	*3		2000-2009	2090-2099	Evans, 2009
		AMP	%	0 ~ -25	SRES A1B	*1		1981-2000	2081-2100	Kim and Byun, 2009
	Armenia	AMT	°C	+1.1 ~ +1.2	SRES A2	MAGICC/SCENGEN (combination of models)		1961-1990	2030	Gabrielyan et al., 2010
		AMT	°C	+3.2 ~ +3.4	SRES A2			1961-1990	2070	Gabrielyan et al., 2010
		AMT	°C	+5.3 ~ +5.7	SRES A2			1961-1990	2100	Gabrielyan et al., 2010
		AMT	°C	+1 ~ +1.1	SRES B2			1961-1990	2030	Gabrielyan et al., 2010
		AMT	°C	+2.9 ~ +3	SRES B2			1961-1990	2070	Gabrielyan et al., 2010
		AMT	°C	+4.8 ~ +5.1	SRES B2			1961-1990	2100	Gabrielyan et al., 2010
		AMP	%	-2 ~ -6	SRES A2			1961-1990	2030	Gabrielyan et al., 2010
		AMP	%	-6 ~ -17	SRES A2			1961-1990	2070	Gabrielyan et al., 2010
		AMP	%	-10 ~ -27	SRES A2			1961-1990	2100	Gabrielyan et al., 2010
		AMP	%	-2 ~ -6	SRES B2			1961-1990	2030	Gabrielyan et al., 2010
		AMP	%	-3 ~ -15	SRES B2			1961-1990	2070	Gabrielyan et al., 2010
		AMP	%	-8 ~ -24	SRES B2			1961-1990	2100	Gabrielyan et al., 2010
		AMT	°C	+1	SRES A2		PRECIS	1961-1990	2030	Gabrielyan et al., 2010
		AMT	°C	+3	SRES A2		PRECIS	1961-1990	2070	Gabrielyan et al., 2010
		AMT	°C	+4	SRES A2		PRECIS	1961-1990	2100	Gabrielyan et al., 2010
		AMP	%	-3	SRES A2		PRECIS	1961-1990	2030	Gabrielyan et al., 2010
		AMP	%	-6	SRES A2		PRECIS	1961-1990	2070	Gabrielyan et al., 2010
		AMP	%	-9	SRES A2		PRECIS	1961-1990	2100	Gabrielyan et al., 2010
Central Asia (5)	*General	AMT	°C	+2.87 ~ +5.49	SRES A1	HadCM3, ECHAM4, ECHAM5, CSIRO-Mk3, CGCM3		1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMT	°C	+2.68 ~ +4.55	SRES A2			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMT	°C	+1.93 ~ +2.49	SRES B1			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMT	°C	+1.93 ~ +3.8	SRES B2			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMT	°C	+3.99 ~ +7.17	SRES A1			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMT	°C	+2.87 ~ +6.42	SRES A2			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMT	°C	+2.49 ~ +4.74	SRES B1			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMT	°C	+2.68 ~ +4.18	SRES B2			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.6 ~ +0.59	SRES A1			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.49 ~ +0.42	SRES A2			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.43 ~ +0.08	SRES B1			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-1 ~ +1	SRES B2			1961-1990	2050	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.77 ~ +0.08	SRES A1			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.43 ~ +0.08	SRES A2			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.43 ~ -0.09	SRES B1			1961-1990	2080	Lioubimtseva and Henebry, 2009
		AMP	mm/d	-0.26 ~ +0.08	SRES B2			1961-1990	2080	Lioubimtseva and Henebry, 2009
	Kazakhstan	AMT	°C	+1.4	Median results of SRES A1F1, A2, B2, B1	CERF98, CSI296, ECH498, CSM_98, HAD300		1961-1990	2016-2045	Kryukova et al., 2009
		AMT	°C	+2.7				1961-1990	2036-2065	Kryukova et al., 2009
		AMT	°C	+4.6				1961-1990	2071-2100	Kryukova et al., 2009
		AMP (rain)	%	+2				1961-1990	2016-2045	Kryukova et al., 2009
		AMP (rain)	%	+4				1961-1990	2036-2065	Kryukova et al., 2009
		AMP (rain)	%	+5				1961-1990	2071-2100	Kryukova et al., 2009
		AMT	°C	+1.2 ~ +1.9	SRES A1F1			1961-1990	2016-2045	Kryukova et al., 2009
		AMT	°C	+2.5 ~ +4	SRES A1F1			1961-1990	2036-2065	Kryukova et al., 2009
		AMT	°C	+5.7 ~ +8	SRES A1F1			1961-1990	2071-2100	Kryukova et al., 2009
		AMP (rain)	%	-2 ~ +8	SRES A1F1			1961-1990	2016-2045	Kryukova et al., 2009
		AMP (rain)	%	-4 ~ +15	SRES A1F1			1961-1990	2036-2065	Kryukova et al., 2009
		AMP (rain)	%	+8 ~ +28	SRES A1F1			1961-1990	2071-2100	Kryukova et al., 2009
		AMT	°C	+1.5 ~ +2.2	SRES B1			1961-1990	2016-2045	Kryukova et al., 2009
		AMT	°C	+1.6 ~ +2.6	SRES B1			1961-1990	2036-2065	Kryukova et al., 2009
		AMT	°C	+3.1 ~ +3.4	SRES B1			1961-1990	2071-2100	Kryukova et al., 2009
		AMP (rain)	%	0 ~ +8	SRES B1			1961-1990	2016-2045	Kryukova et al., 2009
		AMP (rain)	%	-3 ~ +9	SRES B1			1961-1990	2036-2065	Kryukova et al., 2009
		AMP (rain)	%	-2 ~ +13	SRES B1			1961-1990	2071-2100	Kryukova et al., 2009
	Kyrgyzstan	AMT	°C	+4.5 ~ +8.4	A2-ASF	MAGICC/SCENGEN (combination of models)		1961-1990	2100	Iliasov and Yakimov, 2009
		AMT	°C	+3.5 ~ +6.1	B2-MESSAGE			1961-1990	2100	Iliasov and Yakimov, 2009
		AMP	%	-43.4 ~ +59.9	A2-ASF			1961-1990	2100	Iliasov and Yakimov, 2009
		AMP	%	-30.9 ~ +40.9	B2-MESSAGE			1961-1990	2100	Iliasov and Yakimov, 2009
	Turkmenistan	AMT	°C	+4.6	Double CO_2	GISS		1961-1990	2050-2100	MNPT, 2000
		AMT	°C	+4.2	Double CO_2	CCC		1961-1990	2050-2100	MNPT, 2000
		AMT	°C	+5.5	Double CO_2	UK89		1961-1990	2050-2100	MNPT, 2000
		AMT	°C	+6.1	Double CO_2	GFDL		1961-1990	2050-2100	MNPT, 2000
		AMT	°C	+4.8	Double CO_2	GFDL-T		1961-1990	2050-2100	MNPT, 2000
		AMP	%	-56	Double CO_2	GISS		1961-1990	2050-2100	MNPT, 2000
		AMP	%	0	Double CO_2	CCC		1961-1990	2050-2100	MNPT, 2000
		AMP	%	-17	Double CO_2	UK89		1961-1990	2050-2100	MNPT, 2000
		AMP	%	-15	Double CO_2	GFDL		1961-1990	2050-2100	MNPT, 2000
		AMP	%	-4.4	Double CO_2	GFDL-T		1961-1990	2050-2100	MNPT, 2000
Tibetan Plateau		AMP	mm/y	increase	SRES A2	MRI-CGCM2.2	CRIEPI-RegCM3	1979-2005	2046-2055	Takayabu et al., 2007
		AMP	mm/y	increase	SRES A2	MRI-CGCM2.2	MRI-RCM	1979-2005	2046-2055	Takayabu et al., 2007

*[1] CCSM3, CGCM3.1 (T47), CGCM3.1 (T63), CNRM-CM3, CSIRO-MK3.0, ECHAM5/MPI-OM, FGOALS-g1.0, GFDL-CM2.0, GFDL-CM2.1, GISS_AOM, GISS-ER, INM-CM3.0, MIROC3.2 (hires), MIROC3.2 (medres), MRI-CGCM2.3.2
*[2] BCCR-BCM2.0, CCCMA-CGCM3, CCCMA-CGCM3_T63, CNRM-CM3, CSIRO-MK3.0, GFDL-CM2.0, GFDL-CM2.1, GISS_AOM, GISS_EH, GISS-ER, IAP_FGOALS1.0G, INMCM30, IPSL_CM4, MIROC3.2_HIRES, MIROC3.2_MEDRES, MIUB-ECHOG, MPI-ECHAM5, MRI-CGCM2.3.2a, NCAR-CCSM3.0, NCAR-PCM1, UKMO-HADCM3, UKMO-HADGEM1
*[3] BCC-CM1, BCCR-BCM2.0, CCCMA-CGCM3.1 (T47), CNRM-CM3, CSIRO-Mk3.0, GFDL-CM2.0, GFDL-CM2.1, GISS-ER, INM-CM3.0, IPSL-CM4, MIROC3.2, MIUB-ECHO-G, MPI-ECHAM5, MRI-CGCM2.3.2a, NCAR-CCSM3.0, NCAR-PCM1, UKMO-HADCM3, UKMO-HADGEM1

Table 24-5: Description of climate parameter abbreviations used in Tables 24-2 to 24-4.

Variable	Abbreviation	Description
Temperature	AMT	annual mean temperature
	$AMT_{max.}$	annual mean maximum temperature
	$AMT_{min.}$	annual mean minimum temperature
	$HW_{freq.}$	frequency of hot waves per year
	$HW_{dur.}$	maximum duration of consecutive hot days (days with Tmax above 30 Celsius)
	$T_{max.}$	averaged daily maximum temperature
	$T_{min.}$	averaged daily minimum temperature
	FD	number of frost days with Tmin below 0 Celsius
	HWDI	heat wave duration index (defined as the maximum number of consecutive days during the year when the daily maximum temperature was greater than 5 degrees Celsius above the normal maximum temp.
	HD	number of hot days with Tmax above 30 Celsius
Precipitation	$DRY_{max.}$	maximum number of consecutive dry days
	MMP	mean monthly precipitation
	DP≧0.1mm	days when daily precipitation is 0.1mm or less
	AMP	annual mean precipitation /rainfall anomaly
Sea level rise	RSLR	relative sea level rise

Table 24-6: Summary of observed and projected impacts in the water sector.

	Central Asia	East Asia	North Asia	South East Asia	South Asia	West Asia
Observed Impacts	- High impact, mountain glaciers melt (Casassa et al., 2009)	- High impact in arid area, e.g. Mongolia, and northwest China - Groundwater drops in northeast Mongolia - Monsoon rainfall impact on water quality in South Korea - Increased carbon and nutrients from mountainous watershed during typhoons in Japan and Taiwan China		- Precipitation relates to dissolved oxygen, PH, and productivity in Mekong river		
Projected impacts		- Possible positive impact in Yellow River basin -	- In most of Russia, an increase of evaporation in warmer climate and precipitation is projected to have positive impact on water availability (Alcamo et al., 2007)		- Projected heavy impact due to high dependence on irrigated agriculture and melt water in Indus and Brahmaputra (Immerzeel et al., 2010) - Possible increase the risk of floods in Mahanadi (Asokan and Dutta, 2008) - Projected increase of rainfall offset the water demand in Ganges (Fung et al., 2011) - Projected vulnerability in Coastal ground freshwater in South India, Bangladesh and China (Ranjan et al., 2009)	

Table 24-7: Summary of observed and projected impacts in the food sector.

	Central Asia	East Asia	North Asia	South East Asia	South Asia	West Asia
Observed Impacts		In China, assessed rice yield responses to recent climate change at experimental stations for the period of 1981–2005 (Zhang et al. 2010). There was a variable climate to yield relationships. In some places, yields were positively correlated with temperature when they were also positively related with radiation. However, in other places, lower yields with higher temperature was accompanied by positive correlation between yield and rainfall.				In Jordan, in year 1999, the total production and average yield of wheat and barley were the lowest among the years 1996 to 2006.
Projected Impacts	The impacts to food production will vary by country. Cereal production in northern and eastern Kazakhstan can could benefit from the longer growing season, warmer winters and slight increase in winter precipitation, Western Turkmenistan and Uzbekistan, where frequent droughts will 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 China, impacts of climate change to crop productivity have mixed results. Rice yields could decline with increasing temperature if CO2 effect is not considered. With CO2 fertilization, rice yields may increase with higher temperature. In China's most productive wheat growing region, winter wheat yields would increase on average by 0.2 Mg ha-1 in the earlier period in 2015-2045 and by 0.8 Mg ha-1 in the later period in 2070-2099 due to warmer nighttime temperatures and higher precipitation, under A2 and B2 scenarios using HadCM3 model (Thomson et al., 2006). In a wheat-maize cropping system in Huang-Huai-Hai (3H) Plain, China, a 2 and 5 oC increase in temperature, precipitation increasing and deceasing by 15 and 30%; and atmospheric CO2 enrichment to 500 and 700 ppmv would result to in a mean relative yield change (%) (RYC in %) of −10.33% and the lowest and highest RYC values of −46% and 49%, respectively. However with CO2 fertilization a positive change in RYC was obtained (Liu et al. 2010).	In Russia, climate change may also lead to "food production shortfall" which is 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 in the same year 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 SRES.	In Indonesia, the date of rice planting could shift with a marked increase in the probability of a 30-day delay in monsoon onset in 2050 as a result of changes in the mean climate (Naylor et al. 2007).	In Swat and Chitral districts of Pakistan, there were mixed results as well (Hussain and Mudasser, 2007). Projected temperature increase of 1.5 and 3 °C would cause to wheat yields to decline by 7% and 24% respectively in Swat district but would lead to an increase (by 14% and 23% respectively) in Chitral district.	In Western Asia, a rise in CO2 concentration may benefit semi-arid crops by increasing crop water use efficiency and net photosynthesis leading to greater biomass, yield and harvest index (Ratnakumar et al., 2011). For example, wheat and rice grain yield increased by an average of 10-20% at ample N and water with elevated CO2 (350ppm to 700ppm).
		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).			In India, changing climate projected to reduce monsoon sorghum grain yield by 2 to 14% by 2020 with worsening yields by 2050 and 2080 (Srivastava et al., 2010). In the Indo-Gangetic Plains (IGPs), a similar reduction in wheat yields is projected, unless appropriate cultivars and crop management practices were adopted (Ortiz et	In Yarmouk basin, Jordan, simulation with DSSAT showed that wheat and barley yields will decline by 10-20% and 4-8% respectively with 10-20% reduction in rainfall (Al-Bakri et al., 2010).

					al., 2008).	
					In the Indo-Gangetic Plains (IGPs) climate projections based on a doubling of CO2 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 of in the most favorable and high yielding area due to heat stress.	
					In Sri Lanka, tea cultivation at low and mid-elevations are more vulnerable to the adverse impacts of climate change than those 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$34,214 million (+72%) depending on the climate scenarios (Eriyagama et al. 2010).	
					In Sri Lanka, studies on rice production have mixed results (Eriyagama et al., 2010). An earlier study showed that a 0.1-0.5°C increase in temperature could depress rice yield by approximately 1-5%. However, another experiment revealed that rice yields respond positively (increases of 24 and 39% in the two seasons) to elevated CO2 even at higher growing temperatures (>30°C) in subhumid tropical environments.	

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

Crop	Country/ Region	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 the future	Hussain and 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 the 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 the 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 and 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	The replacement of the 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 and 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 the 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 24-9: Summary of adaptation options.

Issues	Country/ Region	Recommended/ Potential Adaptation strategies	Benefits/ Co-Benefits	References
Environmental impacts	Asia	Develop new or transform existing settlements with green infrastructure	Contribute towards low-carbon society	ADB, 2012
Water infrastructure	Bangladesh	Consider factors such as changes in development patterns, water use upstream, land use change and population and economic growth in addition to scenarios.		ADB, 2011a
		Incorporation of climate proofing of infrastructure in the project design		
Disaster resilience (flood risk)	India Bangladesh	Integrated approaches through existing community-based practices and enhancement of social capacity		Surjan and Shaw, 2008; Prashar, et.at., 2012; Rotberg, 2010
		Local government-neighborhood group partnership	Promotion of waste reduction	Surjan and Shaw, 2009
Water resources	India and Nepal	Rainwater harvesting by modifying building bye-laws, providing financial assistance or discounts		UNESCO, 2012; Pandey, et.al., 2003
Flood mitigation	Japan	Underground river consisting of a pipe of diameter 10-12.5 meters and few kilometers long		Zevenbergen and Herath, 2008
Non-structural flood control measures	Japan	Land-use zoning Flood proofing Flood risk mapping Onsite run off control strategies Rainfall storage Infiltration facilities Use of public spaces, such as parks for flood retardation		

Table 24-10: Summary of observed changes and projected impacts for livelihoods and poverty.

Observed change / Impact	**Country/ Region**		**References**
Poor are disproportionately impacted by climate related hazards	East and South Asia		Kim, 2011
Increased migration due to environmental (e.g. rapid onset disasters), social and economic reasons	Mekong region		Warner, 2010; Black et al., 2011
Leave farming due to repeated droughts	South Asia		Kulkarni and Rao, 2008
Loss of crops, income and fallows	Cambodia		Nguyen et al., 2009
Projected Impacts	**Country/Region**	**Projection Details**	**References**
Negative impact on rice crop, increase in food price and cost of living, increased poverty	Asia	GTAP Model, projections for 2030, scenarios: Impacts resulting low, medium and high productivity	Hertel et al., 2010
Loss of livelihoods to indigenous people from declining alpine biodiversity	Tibet/Himalayas	Qualitative observations	Salick et al., 2009; Xu et al., 2009

Table 24-11: Summary of adaptation options for securing livelihoods in Asia.

Aspect/ Issues?	**Country/ Region**	**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 and 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 and 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 and Salick, 2009; Salick et al., 2009

Table 24-12: Location and major characteristics of central Asia glaciations.

Alatai-Sayan mountains					
Geo-coordinates	Total glacier area in 2009 (km^2)	Quantity of glaciers	ELA, ave. (km, a.s.l.) in 2009	Distribution area (km, a.s.l.)	Glacier thickness, ave. (km)
45º-54ºN; 84º–103ºE	1,562	2,340	2.8	2.1-4.5	0.057
Pamir mountains					
36º-40ºN; 66º-76ºE	13,424	11,671	4.6	3.4-7.7	no data
Tien Shan mountains					
39º-46ºN; 69º-95ºE	13,196	10,925	4.4	2.8-7.4	no data

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

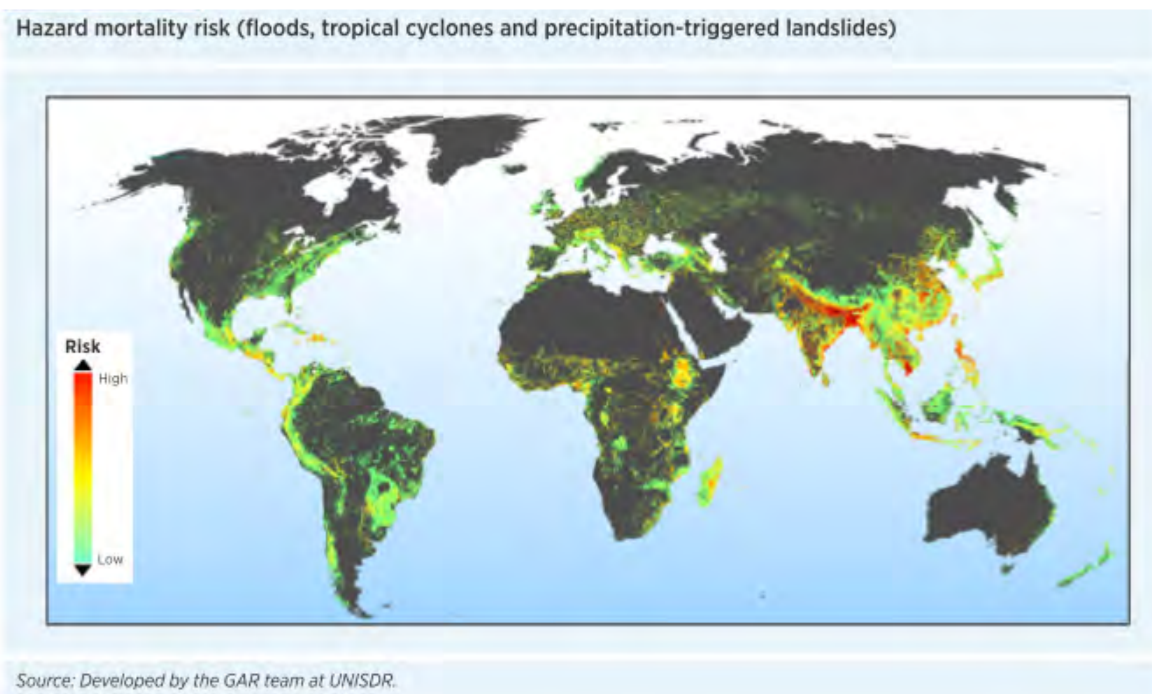

Figure 24-2: Hazard mortality risk. Source: *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. WWAP (World Water Assessment Programme), UNESCO, Paris. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/WWDR4%20Volume%202-Knowledge%20Base.pdf Page 117.

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

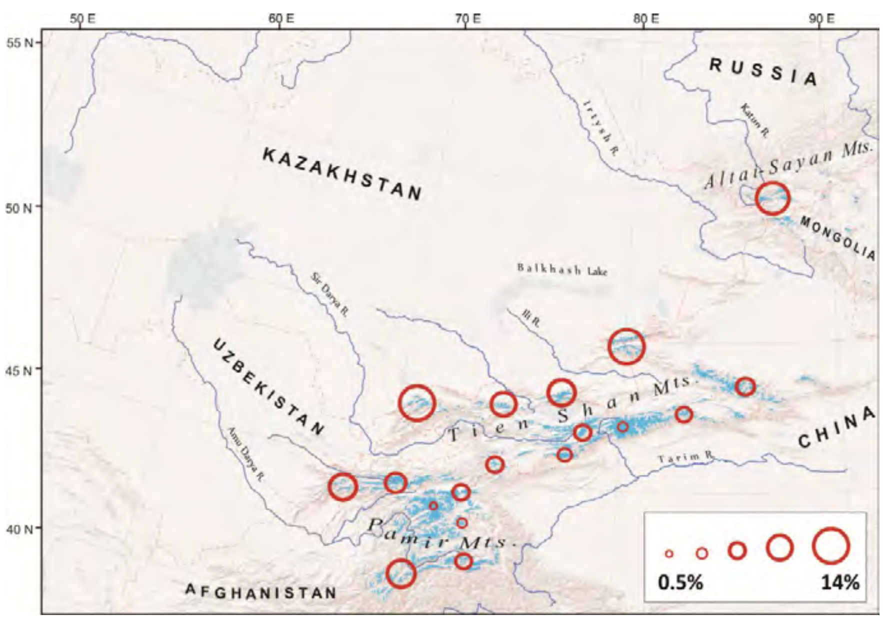

Figure 24-4: The difference in losses of glacier area in Altai-Sayan, Pamir and Tien Shan determined by location of the mountain ridges in relation to major atmospheric moisture flow and by elevation a.s.l. Remote sensing data analysis from 1960s (Corona) through 2009 (Landsat, ASTER and Alos Prism).

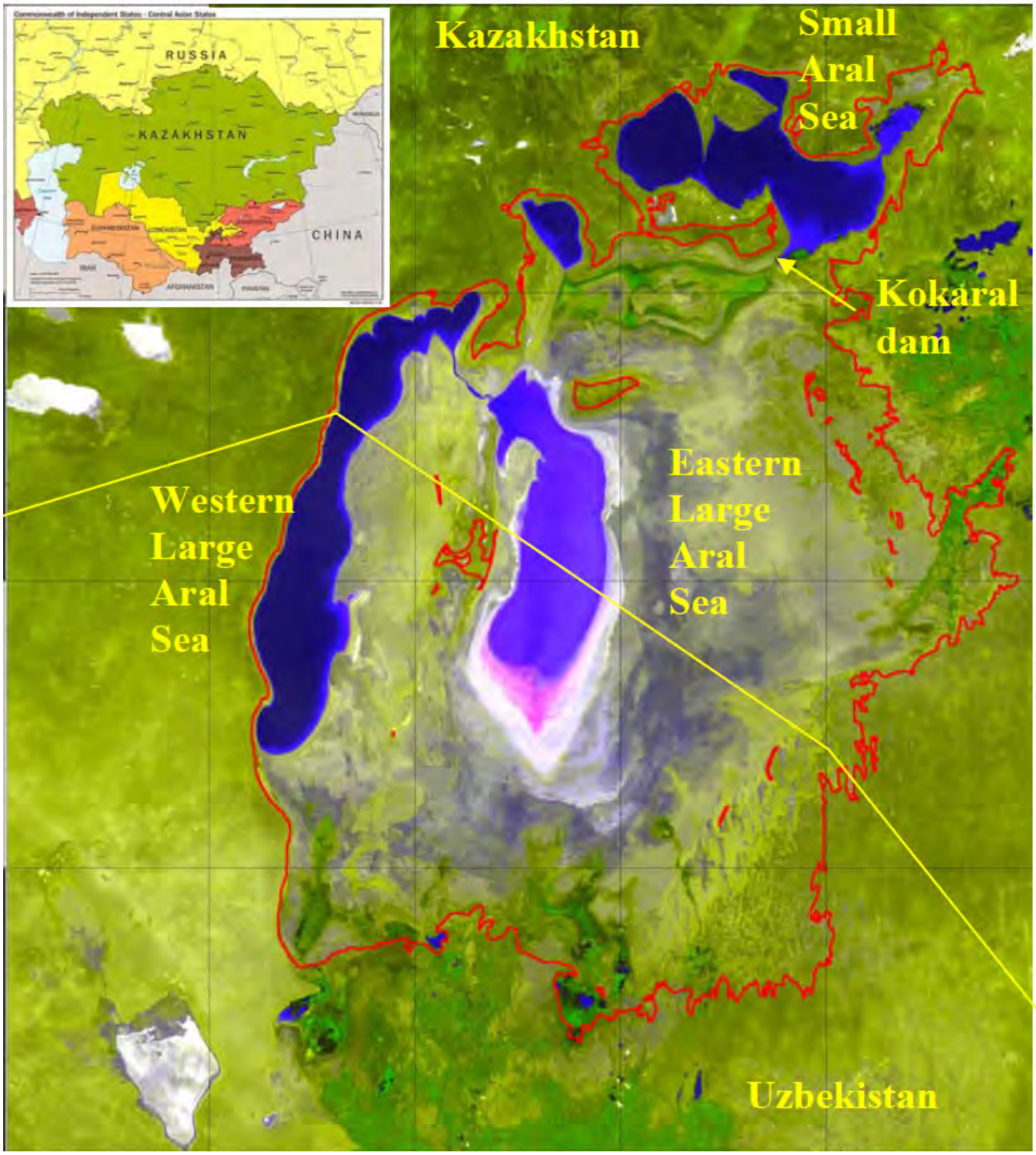

Figure 24-5: The MODIS-Terra satellite image of the Aral Sea on 18 August 2008. Image courtesy by D.M. Soloviev, Marine Hydrophysical Institute, Sevastopol, Ukraine, basing on the data provided by the LAADS Web, NASA-Goddard Space Flight Center (http://ladsweb.nascom.nasa.gov/). Red line shows the Aral Sea coastline in 1960. Yellow line shows the border between Kazakhstan and Uzbekistan.