Chapter 24. Asia

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Executive Summary

Asia has been identified to be among the most vulnerable regions in the IPCC Fourth Assessment Report (AR4) and literature published since then supports this finding [24.2, 24.3, 24.4]. The observed temperature increases over the past 30 years in large parts of Asia are generally within the range of 0.5°C to 1.0°C, although North Asia has larger observed changes. It has become wetter in northern and central Asia but drier in parts of southern Asia. Asia is also at threat because of the changes in frequency and magnitude of extreme events and severe climate anomalies, such as heatwaves, intense rain, floods, droughts and tropical cyclones. The changes will affect not only natural and physical systems but also human systems.

The occurrence of climate-induced disasters and heat stress has increased in Asia and climate change is expected to compound this situation [24.3.2, 24.4.6]. Significant increase of heatwave duration and severity has

been observed in many countries of Asia, including Asian Russia, Mongolia, China, Japan and India. In South Asian countries, flooding has contributed 49% to the modelled annual economic loss of GDP since the 1970s. Urban poor populations often experience increased rates of infectious disease after flood events. Increases in cholera, cryptosporidiosis and typhoid fever have been reported in low- and middle-income countries. Glacier melt in the Himalayas is projected to increase flooding and rock avalanches from destabilized slopes. An increase in losses from flooding in the Xinjiang autonomous region of China seems to be linked to changes in rainfall and melted snow flash floods since 1987. Both upward and downward trends were detected over the last four decades in four selected river basins of the north western Himalaya. Analysis of risk from heavy rainfall in the city of Mumbai, concluded that total losses (direct plus indirect) associated with a 1-in-100 year event could treble in the 2070s compared with current situation (US$690-1,890 million including US$100-400 million of indirect losses), and that adaptation could significantly reduce future damages.

Coastal areas in Asia are increasingly vulnerable to catastrophic disasters [24.4.3]. As a result of climate change, amplification in storm-surge heights and an enhanced risk of coastal disasters along the coastal regions of East, South and South-East Asian countries are likely. There is an increasing likelihood of extreme floods during the period 2050 to 2100 for the Mekong River. Mega deltas are highly susceptible to extreme impacts due to a combination of factors such as high hazard rivers, coastal flooding, and increased population exposure from expanding urban areas with large proportions of high vulnerability groups.

Water resource availability is a major concern in Asia and its scarcity is expected to create major challenges for the region [24.4.1]. Among the countries of Asia, twenty have renewable annual per capita water resources in excess of 3,000 $m^{3,}$ eleven are between 1,000 and 3,000 $m^{3,}$ and six are below 1,000 m^3 (there are no data from the remaining six countries). Glacier melt in Central Asia and the Himalayas is projected to affect water resources within the next x to x decades. This will be followed by decreased river flows as the glaciers recede. 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.

Food production and crop yield in most regions have declined and this trend is expected to continue [24.4.4]. Rice, the staple food in many parts of Asia, is adversely affected by extremely high temperature, especially prior to or during critical pollination phases. Paddy rice in Japan is most vulnerable to cyclone damage for several days around the rice heading day. About xx % of Asian rice areas experience frequent yield loss due to drought, especially in Eastern India and Southeast Asia. In Cambodia, severe drought that affects grain yield mostly occurs late in the growing season, and longer duration genotypes are more likely to encounter drought during grain filling. Since AR4, there have been a number of studies on the impacts of climate change to crop productivity in Asia with varying results. Climate change was projected to reduce rice, wheat monsoon sorghum grain yield by 2 to 14% by 2020 with worse yields by 2050 and 2080 in south Asia and Eastern Asia as rainfall reduced and without CO_2 fertilization. There will be regional differences in the impacts of climate change on food production in Asia, with most regions experiencing a decline while some areas will have increased production. More detailed research shows that impacts to crop production are mainly negative but for some crops it will be positive. Many potential adaptation strategies exist but research is limited.

Climate change is expected to exacerbate human security threats in Asia particularly in relation to resources [24.4.4, 24.4.5, 24.4.6]. Many parts of Asia are already witnessing new threats to human security, brought about by climate change, in addition to traditional security issues that these regions already face. 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 as well as health. 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. It is projected that crop yields could increase/decrease up to xx% in East and South-East Asia while they could decrease up to xx% in Central and South Asia by the mid-21st century. Taken together and considering the influence of rapid population growth and urbanization, the risk of hunger is projected to remain very high in several developing countries.

Extreme climate events will further exacerbate public health problems in vulnerable disaster-prone areas in the Asian region [24.4.6]. Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle associated with global warming. Increases in coastal water temperature would exacerbate the abundance and/or toxicity of cholera in South Asia. Morbidity and mortality of diarrhoeal diseases associated with climate change are expected to increase in South and South-East Asia. The distribution of vector-borne and certain water-borne diseases are projected to expand northwards in North Asia.

Terrestrial and marine ecosystems are increasingly under pressure from both climatic and non-climatic drivers [24.2.2, 24.4.2, 24.4.3]. The evidence for changes in terrestrial ecosystems that can be confidently linked with observed climate change is strongest and most consistent in the north of the region and at high altitudes. In the North Asia, larch forest invasion into tundra for 3–10 m per year was observed in the late 20th century. It is likely that boreal forest will expand northward and eastward, and tundra area will decrease during 21-nd century, however expansion magnitude varies greatly across models. Reduced regeneration and tree growth are likely to cause a retreat of the forest at the forest-steppe ecotone in Mongolia. Substantial retreat of permafrost is expected during the 21st century in Asian Russia and in the Qinghai-Tibet Plateau. At mid latitudes the evidence is widespread and diverse, but the degree of consistency is lower. In the tropical lowlands, in contrast, although climate impacts are expected on theoretical grounds, the evidence for current impacts is still unclear. Satellite data for the past decade (2000-2009) suggests decreased NPP in South-East Asian rainforests, in Central Asia and at high latitudes in West Asia, but increases over most of the rest of the region. Damage due to coastal flooding is sensitive to the change in magnitude of tropical cyclones. Cyclones can also have a large impact on the productivity of coastal waters through increased nutrient run-off and water circulation. Most of Asia's non-Arctic coastal systems are under such severe pressure from non-climate human impacts that climate impacts would be hard to detect, but there is increasingly strong evidence that rising sea-surface temperatures are responsible for a massive increase in coral-bleaching events across tropical Asia. Grassland fire disaster is a critical problem in China due to global warming and human activity. 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.

Multiple stresses caused by rapid urbanization, industrialization and economic development are likely to be compounded by climate change [24.4, 24.5, 24.6]. The emergence of infectious diseases, environmental pollutants and health inequality from extreme events are likely to be exacerbated by rapid urbanization; it is argued that health related risks could potentially worsen in Asian countries. Tropical cyclone mortality risk is highly geographically concentrated in Asia, and takes both a relative and absolute high exposure to industrialization and GDP. According to statistics collected by the insurance sector, about 1/3 of reported catastrophes globally occur in Asia, while the proportion of fatalities is about 70%. The research revealed that a typhoon which is 1.3 times as strong as the design standard with a sea level rise of 60cm would cause damage costs of JPY298, 4,001, 2,687 billion in the investigated bays respectively. Some studies argue that economic restructuring and the process of market transition in those fast developing Asian countries could potentially help to decrease vulnerability and the economic impacts of disasters.

24.1. Introduction

Asia is defined here as the land and territories of 52 countries/regions. It can be broadly divided into six sub-regions based on geographical position and coastal peripheries (Table 24-1). These are North Asia (2 countries), East Asia (7 countries/regions), Southeast Asia (12 countries), South Asia (8 countries), West Asia (18 countries) and Central Asia (5 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 km^2 (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). Much of this population will be highly sensitive to changes in climate.

[INSERT TABLE 24-1 HERE
Table 24-1: The 52 countries/regions in the six sub-regions of Asia.]

24.2. Major Conclusions from Previous Assessments

24.2.1. Climate Change Impacts in Asia

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 /century, with most pronounced increases noted in North Asia. There has also been new evidence on recent trends, particularly on the increasing tendency in the intensity and frequency of extreme weather events in Asia over the last century and into the 21st century. In addition, the variability in rainfall trends has been observed during the past few decades all across Asia. 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. Precipitation projections indicate an increase in most of Asia during this century. Also an increase in extreme weather event occurrences is projected for South Asia, East Asia, and South-East Asia, followed by an increase of intensity in tropical cyclones in the same regions, due to a rise in sea-surface temperature. The coastal areas of Asia have reported accelerated sea-level rise relative to the long-term average.

Observed climate change impacts. Production of rice, maize and wheat 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. 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. 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. Many plant and animal species are reported to be moving to higher latitudes and altitudes as a consequence of observed climate change. Deaths and disorders from heatwaves and outbreaks of infectious diseases linked to different climate variables (e.g. floods, temperatures, droughts), mainly in low-income areas with poor water and sanitation safety have been reported in many regions.

24.2.2. Vulnerabilities and Adaptive Strategies

Vulnerable sectors. Studies suggest that substantial decreases are probable not only in cereal production potential, but also in livestock, fishery, and aquaculture net primary productivity. Increasing urbanization and population in Asia will likely result in increased food demand and reduced food supply due to limited availability of cropland area and yield declines. Food insecurity and loss of livelihood are likely to be further exacerbated by the loss of cultivated land and nursery areas for fisheries. 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 likely to increase substantially in absolute terms. 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 are likely to be exacerbated by climate change. AR4 reported that up to 50% of the Asia's total biodiversity is at risk due to climate change. Apart from substantial direct impacts on public health and livelihood, climate-change-attributed diarrhea and malnutrition, as well as heat stress, climate change is also expected to affect the economical aspect of Asian countries by altering the current demand and supply patterns of crucial revenue producing sectors.

Vulnerable areas. Regions of arid and tropical Asia can be considered most vulnerable to climate change, due to the exposure of their population to severe water stress and possible increase of cholera cases, and higher endemic morbidity and mortality due to diarrheal disease associated with floods and drought. The combination of malnutrition and diarrhea will increase in low-income areas. Increases in coastal water temperature would exacerbate the risk of cholera in South Asia. Decrease in crop yields is also to be expected in South Asia, as well as some regions of temperate Asia. Glaciers over Tibetan Plateau are likely to shrink at an accelerated pace. Projected sea-level rise is very likely to result in significant losses of coastal ecosystems, along with increased risk of flooding on the coasts of South and South-East Asia. Stability of wetlands, mangroves and coral reefs around Asia is likely to be increasingly threatened.

Adaptation strategies. More common adaptation measures 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. In the water sector focus should be placed on dealing with water use inefficiency, and promotion of recycled water which could prove useful in many agricultural areas in Asia. Along the coast, protection, such as dike heightening and strengthening, should remain a key focus in responding to sea-level rise. Most forests in Asia necessitate comprehensive inter-sectoral programs that combine measures to control deforestation and forest degradation. Implementation of monitoring and warning systems will most likely be helpful in reducing the impacts of climate change of human health. 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 including spatial and temporal uncertainties associated with forecasts of regional climate, limited national capacities in climate monitoring and forecasting, and lack of co-ordination in the formulation of responses. In order to address such constraints the following measures could prove useful. 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.

24.3. Observed and Projected Climate Change

24.3.1. Observed Climate Trends and Variability

As in AR4, the characteristics of observed climate trends and variability in Asia are overall increasing trends in surface air temperature; the warming trends have been observed in countries and regions such as Russia, Mongolia (North-Western Khentey Mountains), Central and South Asia, Tibetan Plateau, Iran, Korea, Japan, China, India, Eastern Gangetic Plains, Nepal, Pakistan, Sri Lanka and Bangladesh (Li *et al.*, 2007; Dulamsuren *et al.*, 2010; Klein Tank *et al.*, 2006; Lioubimtseva and Henebry, 2009; Kim and Roh, 2010; Schaefer and Domroes, 2009; Wang *et al.*, 2008; Rahimzadeh, 2009; Fujisawa and Kobayashi, 2010; Ren *et al.*, 2005; Ren *et al.*, 2008; Lal, 2003; Ganguly, 2011; Roy and Balling, 2005; Sharma *et al.*, 2007; Shrestha and Aryal, 2011; Sajjad *et al.*, 2009; Khattak *et al.*, 2011; De Costa, 2008; Shahid, 2010a).This increase is observed especially both in winter and summer in North-Western Khentey Mountains (Dulamsuren *et al.*, 2010), and in winter in Korea and Pakistan (Kim and Roh, 2010; Khattak *et al.*, 2011), with the trends stronger in winter in such countries as Japan and Bangladesh (Schaefer and Domroes, 2009; Shahid, 2010a). Significant decreasing trends in summer diurnal temperature range are observed in North-Western part of Kashmir, India (Roy and Balling, 2005). Temperature increases are most pronounced in Japan (Tokyo), Mongolia (North-Western Khentey Mountains) and Pakistan (Karachi) (Japan Meteorological Agency, 2009, cited by Fujibe, 2011; Dulamsuren *et al.*, 2010; Sajjad *et al.*, 2009). Urban heat island too has an enormous effect on the temperature increase in Tokyo. The increase in the annual mean temperature (AMT) in North-Western Khentey Mountains was between1.2-4.4 ◦C in 45-69 years (Dulamsuren *et al.*, 2010); the AMT increase is observed in large cities in Japan, such as Tokyo (3.3◦C/century over 1931 to 2008) and Hiroshima (2.1◦C/century during the same period) (Japan Meteorological Agency, 2009, cited by Fujibe, 2011); in China, 0.22◦C/decade during 1951 to 2001 (Ren *et al.*, 2005); in North China, 0.29◦C/decade (Ren *et al.*, 2008); and in India, 0.68°C/century over 1880 to 2000 (Lal, 2003) ; in Karachi, 2.25◦C during 1947 to 2005 (Sajjad *et al.*, 2009).

Precipitation changes in Asia over the past several decades are characterized by inter-regional, inter-seasonal and temporal variability. Significant decadal variations have been observed in South, Southeast and central West China (Zhang *et al.*, 2009); and interannual variability is observed in North Asia, East Asia, India and North-Western Khentey Mountains (Li *et al.*, 2007; Xu *et al.*, 2008; Preethi *et al.*, 2011; Dulamsuren *et al.*, 2010). Decreasing precipitation trends are observed in Sri Lanka; the Western Tibetan Plateau; parts of Southern Asia; and the Brantas

Catchment Area, East Java (De Costa, 2008; Xu *et al*., 2008; Mertz *et al*., 2009; Aldrian and Djamil, 2008), whereas increasing trends are observed in Russia; the Eastern and Central Tibetan Plateau; Northern and Central Asia; Bogor, West Java; Bangladesh; and the Jhikhu Khola Watershed, Nepal (Li *et al*., 2007; Xu *et al*., 2008; Mertz *et al*., 2009; Watanabe *et al*., 2010; Shahid, 2010a, b; Gautam *et al*., 2010). The amount of summer total precipitation is on an increasing trend in South-Eastern and North-Western China and on a decreasing trend in Central China, South-Western and North-Eastern Asia; this tendency also appears in summer precipitation days (Yao *et al*., 2008). Variability has also been observed in annual precipitation (AP): in South Asia, AP fluctuated between -100 and +50 mm between 1961 and 2006 (Dulamsuren *et al*., 2010). An increase in AP is observed in the western part of Bangladesh (Shahid, 2010a), in the Jhikhu Khola Watershed, Nepal, (Gautam *et al*., 2010), and in Bogor, West Java (Watanabe *et al*., 2010), while declining trends of decadal mean AP are observed over 140years in Sri Lanka (De Costa, 2008). Listed in Table 24-2 are main characteristics of observed surface air temperature and precipitation in Asian sub-regions.

[INSERT TABLE 24-2 HERE
Table 24-2: Summary of key observed past and present climate trends and variability.]

24.3.2. Observed Changes in Extreme Climate Events

New insights into increasing and decreasing tendencies of the frequencies and intensities [further literature research needed for “intensities”] of extreme weather events recently observed in Asia are described below and summarized in Table 24-3. [Further literature research needed for “the frequency and intensity of extreme weather events associated with El-Nino.”]

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

Warm day-times and nights are significantly increasing in such region as West Asia, South Asia and South-East Asia coasts and North-Eastern Siberia; they are, in contrast, significantly decreasing in regions including Mongolia, North China, Afghanistan and Pakistan, and Malaysia (Fang *et al*., 2008). Regional wet heatwaves are more frequent and intense in China (Ding and Qian, 2011); more frequent, longer heatwaves have been observed in India (Ganguly, 2011). [Further literature research for “heatwave damage.”] Extreme warm-month events have smaller variability over Tibetan Plateau, North China plain and coastal area of South China, larger variability over North China (Wan, 2009).

Variability in the frequency and intensity [further literature research needed for “intensity”] of extreme rainfall has been observed in each Asian country: the observed trends show an increasing pattern in terms of its frequency and intensity in Korea (Im *et al*., 2011; Ho *et al*., 2003; Boo *et al*., 2006 and Im *et al*., 2008b, cited by Im *et al*., 2011), Japan (Fujibe *et al*., 2006; Fujibe, 2008a), with its frequency on the rise in South East China (Yao *et al*., 2008) [further literature research needed to find out if this is for “frequency”], many parts of South Asia (Lal, 2011) including India (during the monsoon season) (Goswami *et al*., 2006, cited by Preethi *et al*., 2011) and South-East Asia (Lau and Wu, 2007, cited by Chang, 2011); a decreasing pattern in Central India(Yao *et al*., 2008). [Further literature research needed for “frequency of occurrence of more intense rainfall events.”][Further literature research needed for “landslides, and debris and mud flows.”] There are increasing trends in the intensity of extreme wet days, and a significant decrease in the frequency of extreme wet days is observed in some parts of Peninsular Malaysia (Zin et at., 2010). In Eastern part of Russia, speeds of the increase in heavy precipitation are lower and those of decrease, higher, than in Western part (1936-2000) (Bogdanova *et al*., 2010). Severe floods have been on an increase in Poyang Lake, China (Shankman *et al*., 2006), and South Asia including India and Pakistan (Mirza, 2011); human and economic damage from recent massive floods in Bangladesh is tremendous (Mirza, 2011).

The increase in droughts frequency is observed in Mongolia and China (Munslow and O'Dempsey, 2010).Soil moisture droughts have become more severe, prolonged, and frequent during the past 57 years in China, especially northeastern and central China (Wang *et al*., 2011). [further literature research needed for “the attribution of increasing frequency and intensity of droughts to summer/drier months and ENSO.”]

There is an increasing frequency and intensity of tropical cyclones in South-East Asia (Chang, 2011), and a decreasing frequency over most of China except at such locations as low reach of Yangtze River, (Ying, 2011), the East China and Philippine Sea (Ho *et al*., 2004), and India (Srivastava *et al*., 2000, cited by Mirza, 2011). There has been an increasing typhoon influence in the subtropical East Asia and considerable decrease over South China Sea (1965-2003) (Wu *et al*., 2005). [further literature research needed to see if the damage by the cyclones has been significantly increasing.].

24.3.3. Assumptions about Future Climate Trends

Since 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. [No scientific information on climate change in Asia, based on RCPs is available because the new climate scenarios are under development.]

Under the process of assessing climate change for the purposes of AR5, scenarios of Representative Concentration Pathways (RCPs) were developed, in which the full 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*.: The next generation of scenarios for climate change research and assessment, Nature, Vol.463, pp.747-756, 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*.,: The next generation of scenarios for climate change research and assessment, Nature, Vol.463, pp.747-756, 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. [Because SSPs have not been developed yet, socio-economic scenarios in Asia will be added when information is obtained.]

24.3.4. Projected Climate Change

A snapshot of the projections on likely increase in area-averaged seasonal surface air temperature and % change in area-averaged seasonal precipitation (with respect to the baseline period 1961 to 1990) for the seven sub-regions of Asia is being prepared. A future increase in temperature is projected in all regions of Asia including North Asia (Mongolia), Tibetan Plateau, South-East Asia (Indochina Peninsula), South Asia (Indian Sub-continent), East Asia (Korea, Japan, China), Central Asia and West Asia (Takayabu, 2007; Tang *et al*., 2009; Yang, 2010; Lioubimtseva and Henebry, 2009; Evans, 2009). Significant warming is projected in Tibetan Plateau, Korea and South-East China in the future (Wang *et al*., 2008 and You *et al*., 2008a, cited by Kang *et al*., 2010; Im *et al*., 2011; Chen *et al*., 2011).In East Asia, larger temperature increases are projected over high-latitude continent and smaller over low-latitude maritime area (Liu *et al*., 2011); in Tibetan Plateau the warming is more prominent at higher elevations than at lower elevations, especially during winter and spring seasons (Liu *et al*., 2009). Summer temperature increase is projected in Asia Minor, parts of Russia and Korea (Ekstrom, 2007; Bae *et al*., 2008, cited by Kysely´ and Kim, 2009); temperature increase is stronger in winter in China (Tang *et al*., 2009); projected increases are particularly high in summer and fall, but lower in winter in Central Asia (Lioubimtseva and Henebry, 2009).An increase in mean temperature of 2.0-2.5°C in the mid-21st century (relative to 1971 to2000) is projected in Korea (Kysely´ and Kim, 2009) and 1.5°C in East Timor (Cardno Acil and KWK Consulting, 2010). By 2050, temperature rises are projected to be 1 to 2.58°C in Western China (Munslow and O'Dempsey, 2010); 2.0°Cin India (Kumar *et al*., 2010); and 1.4°Cin Bangladesh (Agrawala, 2003). By 2100, the temperature is expected to increase 2-4°C in Vietnam (Cuong, 2008, cited by ADB, 2009), 2.1-3.4°C in Indonesia (Boer and Faqih, 2005, cited by ADB, 2009) and 2.4°C in

Bangladesh (Agrawala, 2003). Substantial warming will be observed both day and night in India (Kumar *et al*., 2010), whereas greater increase is projected at night than day-time in South-East Asia (Chotamonsak *et al*., 2011).

An increase in precipitation is projected in most of Asia with the increase considerably greater in higher latitude areas (Kim and Byun, 2009); the precipitation is expected to increase in western and southern Japan (Nakamura *et al*., 2008; Kusunoki and Mizuta, 2008). By contrast, decreased precipitation is projected in West Asia, especially in Syria and its vicinity (Kim and Byun, 2009). The largest decrease is projected in the Eastern Mediterranean, Turkey, Syria, Northern Iraq, Northeastern Iran and the Caucuses with significant decreases in Western Syria and nearby Turkey by 2050 (Evans, 2009). Annual mean precipitation is projected to increase in parts of Russia, Korea, Japan, Indian sub-continent including southern India, Tibetan Plateau and Mongolia (Kim and Byun, 2009; Takayabu, 2007). The annual mean precipitation (AMP) in the Indochina peninsula is reported to increase in one study (Kim and Byun, 2009) and to decrease in another (Takayabu, 2007). The AMP increase is projected in southeast and north China (Takayabu, 2007) with the increase significant in Eastern and Northeast China (Kim and Byun, 2009; Tang *et al*., 2009); many regions of Southwest and Northwest China will become drier (Tang *et al*., 2009). Annual precipitation in most areas of Vietnam is projected to increase by 5–10% toward the end of this century (Cuong, 2008, cited by ADB, 2009), and the changes range from -2 to +15% in Singapore (Ho, 2008, cited by ADB, 2009). Projected changes in annual rainfall are 2 to 6% in East Timor (Cardno Acil and KWK Consulting, 2010). Seasonally, significant decrease in precipitation is projected for summer and fall in Central Asia (Lioubimtseva and Henebry, 2009); future temperature increases in Tibetan Plateau may lead to further enhanced summer frontal rainfall in East Asia (Wang *et al*., 2008). An increase in summer precipitation is projected in South and East Asia (Kim and Byun, 2009; Kripalani *et al*., 2007). Rainfall will increase in summer and decrease in winter over the regions including eastern China (Liu *et al*., 2011). In summer, the enhanced spring precipitation in South China and Central China appears in a broader area of East Asia, extending into North China and Korea (Lu, 2007).The wet season will become wetter and the dry season, drier in South-East Asia (ADB, 2009). In Indonesia seasonal rainfall would increase consistently between 2020 and 2080 except in September to November (Boer and Dewi, 2008, cited by ADB, 2009). In East Timor the precipitation tends to decrease slightly in summer, increase in spring and winter (Cardno Acil and KWK Consulting, 2010).

An increase in occurrence of extreme weather events including heatwave and intense precipitation events is also projected in Asia: heatwave is projected to increase in East Asia and Tibetan Plateau (Clark, 2006; Yang *et al*., 2010); and intense precipitation, in South Asia (e.g. Bangladesh, Central India), East Asia (e.g. Japan, most of China), South-East Asia, North Asia, Central Asia and Tibet (Kamiguchi, 2006; Rajeevan *et al*., 2008; Liu *et al*., 2011 ; Nakamura, 2008 ; Zhang *et al*., 2006) along with an increase in the interannual variability of daily precipitation in the Asian summer monsoon [further literature research needed for “an increase in interannual variability of daily precipitation”]. Extreme daily precipitation, including that associated with typhoon, would be further enhanced over Japan due to the increase in atmospheric moisture availability [further literature research needed for “extreme daily precipitation”]. The heatwave recurrence interval in Korea is estimated to decrease to around 10 year in the period from 2041-2050 (Kysely’ and Kim, 2009).The intensity, duration and frequency of future heatwaves are also projected to increase in East Asia (Clark, 2006); Hot events are expected to be more severe in Korea (Boo *et al*., 2006). The duration of heatwaves is expected to change from 5-10 days (present) to 7-14 days (future) with the longest durations in western Northwest China (Yang *et al*., 2010); significant increases in annual heatwave duration are projected over southeast China (Chen *et al*., 2011). The heatwave duration index is projected to increase by 2 days by 2050 in East Timor (World Bank, 2009, cited by Cardno Acil and KWK Consulting, 2010). In the Yangtze River basin, China, extreme heavy precipitation is projected more frequently in the future (Kamiguchi, 2006; Su *et al*., 2009); heavy rain proportion is projected to increase in some parts of southeast China in future (Chen *et al*., 2011). In Korea the frequency and intensity of heavy precipitation is projected to increase with precipitation events less frequent and heavier in the future (Im *et al*., 2011). The intensity of a cumulative rainfall sequence is projected to increase, and its frequency is to decrease, which indicates a tendency for extreme rainfall events to become fewer but more intense (Cardno Acil and KWK Consulting, 2010).Seasonally, there will be frequent extreme wet summer, autumn and spring, and frequent extreme dry spring, winter and summer in the 2090s in East Asia (Liu *et al*., 2011).

Future projections indicate a reduction in the frequency of tropical cyclones in the Western North Pacific, coastal regions of South-East Asia (Murakami, 2011), the East China Sea (Orlowsky, 2010) and East Timor (Abbs, 2010, cited by Kirono, 2010) , and an increase in the Bay of Bengal (Unnikrishnan *et al.*, 2006).The proportion of intense typhoons with landfall is expected to increase in the East China Sea (Orlowsky, 2010).An increase of X to X % in tropical cyclone intensities for a rise in sea surface temperature (SST) of X to X C is projected in XXX Asia [further literature research needed for "increase in TC intensity and SST"].The intensity of tropical cyclones is likely to increase in Japan (Esteban and Longarte-Galnares, 2010). Amplification of storm-surge heights could result from the occurrence of stronger winds, with increase in SST and low pressures associated with tropical storms resulting in an enhanced risk of coastal disasters along the coastal regions of XXX [further literature research needed for increase in "storm-surge height and its causes"]. A 50-year storm surge is projected to be higher by 0.5-0.7m in the Bay of Bengal (Mitchell *et al.*, 2006).

The average rate of observed sea-level rise (SLR) in many parts of Asia is higher than the global average: the rate of SLR is 2.77 mm/yr, which is 1.6 times greater than the global average, in the East Asia; 6.2 mm/yr, several times higher, at the Yangtze River mouth (Doong, 2009); 2.5 mm/yr in the past 30 years at Chinese coasts (State Oceanic Administration of China, 2008, cited by Doong, 2009), which is 1.4 times greater than global average (Doong, 2009); 1-8mm/yr in Indonesia (The State Ministry of Environment, 2007, cited by ADB, 2009); 8.7 mm/yr in Solomon Islands and 8.1 mm/yr in Papua New Guinea (Mitchell, 2009); 2-3 mm/yr in Vietnam (Cuong, 2008, cited by ADB, 2009). Average sea levels have been recently higher in Thailand (Jesdapipat, 2008, cited by ADB, 2009). An average tide level of 3.3 m was also observed in Singapore (Ho, 2008, cited by ADB, 2009).In the Coral Triangle the SRL is projected to increase more rapidly than before 2050 (McLeod, 2010). Future projection suggests an increase in SLR in many Asian regions: in Malaysia the SRL is 0.16 m under A2 scenario in 2050; in Papua New Guinea, 0.17m; in the Philippines, 0.17m; and in Solomon Islands, 0.16m (McLeod, 2010). The increase is likely to be 0.3-0.1m in Bangladesh by 2100 in Bangladesh (Agrawala, 2003), and close to the global mean of 0.21-0.48m under X scenario by 2100 in Singapore (Ho, 2008, cited by ADB, 2009), whereas the SLR is projected to be 0-0.01cm less than the global mean in East Timor (O'Farrell, 2008, cited by Kirono, 2010). The future SLR in East Timor is 0.16 m under A2 scenario in 2050 in one article (McLeod, 2010), while it is 0.11 to 0.35 m under X scenario by 2050 in another (Anonym. 2010, cited by Kirono, 2010).

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 rainfall and irrigation. Hence, adequate water supply is one of the major challenges in Asia. Growing demand for water is driven by soaring population, increasing urbanization, and thriving economic growth. Arid countries of 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 in Central Asia is increasing tension between the region's countries. The increasing rate of glacier retreat in the Himalayan region will have negative impact on river runoff and with it also a negative impact on water availability and agriculture in river basins inhabited by over 1 billion people. Tropical Asia will experience severe dry and wet spells that will reduce water supply reliability and increase chances of flooding. Even through precipitation in Northern and temperate Asia is expected to increase overall; socio-economic development will pose a challenge to freshwater resources.

24.4.1.2. Observed Impacts

It has been estimated that a particularly high level of water stress occurs over most of the highly important agricultural areas of Southwest Russia, due to a high level of water withdrawals relative to available water resources (Alcamo *et al.*, 2007) The most recent decade has seen sharply decreasing groundwater levels, in the Kherlen River basin, a relatively pristine area in northeastern Mongolia, yet the absence of a clear long-term trend is generally consistent with studies regarding trends of other components of the hydrological cycle in Mongolia and neighboring regions at similar latitudes (Brutsaert and Sugita, 2008).

In a study specifically dealing with the surface water quality in the lower Mekong, negative significant correlations were generally found between precipitation (or discharge flow) and DO, pH and conductivity (Prathumratana *et al.*, 2008 in Delpla *et al.*, 2009). In South Korea increasing intensity of monsoon rainfalls during recent decades has contributed to the deterioration of water quality in many reservoirs and rivers (Park *et al.*, 2010). Marked increases in the export of carbon and nutrients from mountainous watersheds have also been observed in Japan and Taiwan of China during recent typhoons (Zhang *et al.*, 2007b; Goldsmith *et al.*, 2008 in Park *et al.*, 2010). The surface resources of Central Asia are primarily generated in mountain glaciers. A decrease of glacial volume and area has been documented in the mountains of Tajikistan and Kyrgyzstan (Meleshko, 2004 in Lioubimtseva and Henebry, 2009).

24.4.1.3. Projected Impacts

Asia's water towers are threatened by climate change, yet the effects on water availability and food security in Asia differ substantially among river basins and cannot be generalized. In the Indus and Brahmaputra basins are affected severely owing to the large population and the high dependence on irrigated agriculture and meltwater. In the Yellow River, climate change may even yield a positive effect in the dependence on meltwater is low and a projected increased upstream precipitation, when retained in reservoirs, would enhance water availability for irrigated agriculture and food security (Immerzeel *et al.*, 2010). Throughout much of Russia a warmer climate would decrease water availability, but on the other hand precipitation will increase. Alcamo *et al.* pointed out that water availability would increase over more than 90% of the country, with an exception of the key agricultural zone of the Southwest where water availability decreases because of climate change (2007). In China, hydrological simulations driven by PRECIS climate scenarios suggest increases of around 20% in total water availability for the 2020s, and 18% for the 2040s. However, the overall results suggest that there will be insufficient water for agriculture in China in the coming decades, due to increases in water demand for non-agricultural areas (Xiong *et al.*, 2010). The water demand in most countries of South Asia is gradually increasing because of increases in population, irrigated agriculture and growth in the industrial sectors. Changes in water supply and demand caused by climate change in South Asia will be overlaid on the top of changing water use. The projected changes in hydrological parameters over South Asia would have considerable direct and indirect effects on the agricultural sector in the region (Lal, 2011). In a study of the Mahanadi River Basin, the future water availability forecast indicated an escalating trend in river runoff thereby alarming flood for the month of September, yet the outcomes for April indicate an accelerating water scarcity (Asokan and Dutta, 2008). The same study concluded that water demand would reach its peak around 2050, after which it should decrease owing to the assumed regulation of population. Another study pointed out that in the Ganges the effects of climate change could become large enough to offset the large increases in demand in a +4ºC world (Fung *et al.*, 2011). Given already a very high level of water stress in many parts of Central Asia, projected temperature increases and precipitation decreases in the western part of Kazakhstan, Uzbekistan, and Turkmenistan are very likely to exacerbate the problems of water shortage and distribution (Lioubimtseva and Henebry, 2009). Economies of countries in the Syr Darya and Amu Darya rivers catchment are highly dependent on irrigated agriculture. For example, according to World Bank data, the contribution of agriculture to the national GDP in the case of Uzbekistan was 34% in 2000, and 23% in 2008 (2009, in Schlüter *et al.*, 2010). 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). A study evaluating coastal fresh water resources over the next century showed that most of the coastal areas in Asia show medium reduction, except South-East Asia. The same study devised the most vulnerable regions by considering future population in the calculation. The results show that South Asia (particularly South India and Bangladesh region) and China are showing the highest vulnerability regarding future fresh groundwater supply. In contrast, Japan, due to its higher availability of fresh groundwater and lower population density, creates less vulnerability. (Ranjan *et al.*, 2009) Huang *et al.* showed in their study that the content of dissolved salts in the Salween, Mekong, Yangtze, and Yarlung Tsangpo rivers is relatively high compared to waters from other parts of the world. Further water quality degradation can be expected in the near future due to e.g. intensified weathering and erosion processes caused by global climate change and rapid development of mining operations in the region (2009). Increasing variability in winter and summer precipitation across North East Asia over recent decades has been predicted to accelerate (Chung *et al*., 2004; Im *et al*., 2008 in Park *et al*., 2010). Likely are also major changes in the water cycle, which in return will likely lead to more frequent occurrence of extreme monsoon rainfalls, as predicted for other parts of the world (Knapp *et al*., 2008 in Park *et al*., 2010). AR4 previously reported that projected warming over the Tibetan plateau is estimated to be 2.1-7.5 °C, followed by an overall increase in precipitation. There is already overwhelming evidence of rapid deglaciation in the Himalayas. As glaciers are an important source of water to the rivers of Nepal, as well as India, widespread deglaciation is certain to have an impact on a regional scale on water resources (Shrestha and Aryal, 2011). A study on the impact of climate change on the water resources in the Hindukush-Karakorum-Himalaya region showed that under a 50% glacier scenario there would have increased discharge up to 60% and 88% depending on the model used. For the 0% glacier scenario under climate change, a drastic decrease in water resources, of up to 94%, has been estimated by one of the models, while the other shows a decrease up to 15% (Akhtar *et al*., 2008). Furthermore, glacial melt in the Pamir and Tien-Shan ranges is projected to increase, initially increasing flows in the Amu Darya, Syr Darya, and Zeravshan systems for a few decades, followed by severe reduction of the flow as the glaciers disappear (Glantz, 2005 in Lioubimtseva and Henebry, 2009). The increasing frequency of droughts and floods in South Asia would continue to seriously disrupt food supplies on year to year basis. (Lal, 2011) Results of the sensitivity analysis on flood safety of Yongdam Dam in South Korea have revealed that even though future reliability is slightly increased, the resiliency is decreased 21.6% and vulnerability is increased 35.6%. In other words, it is likely that the number of flood events remains almost the same, but the magnitude and recovery from a single event become worse. Also the same study pointed out to an increase in average streamflow of 38.7% for the B1 scenario, and 14.3% increase of variability. (Kang *et al*., 2007).

In a study conducted by the World Bank, the Bangkok Metropolitan Administration area and Samut Prakarn Province will have 30% more inundated area in 2050 compared with the 2008 equivalent scenario. Much of increase will be in the western areas of the metropolis where protection structures are less developed. Flood volume is expected to increase by the same %age as precipitation, but flood peak discharge will increase more (2009, in Webster and McElwee, 2009).

24.4.1.4. Vulnerabilities to Key Drivers

Key drivers that can be attributed to climate change impact on freshwater resources are identified in insufficient water resource management capacity of developing countries, rapid economic and population growth. Mega cities in Asia are extremely vulnerable to flooding events, owing to their densely populated environments, that provide homes to often migrant and unregistered population settled in inadequate housing. Also based on current knowledge, the rivers most likely to experience the greatest loss in water availability due to melting glaciers are the Indus, Tarim, Yangtze, Brahmaputra, and Amu Darya (Xu *et al*., 2009).

Central Asian countries of the Syr Darya river basin, while under Soviet control, had a basin-wide water management, but after 1991, uncoordinated competition between the catchment’s upstream (Kyrgyzstan, Tajikistan) and downstream (Uzbekistan, Turkmenistan, Kazakhstan) countries manifested high level political conflicts, particularly between Uzbekistan and its two upstream neighbors. One view of the study that reported on this issue was that increasing water scarcity caused by climate change will result in more conflict between the riparian countries. The other view is that climate change will in the short to medium term lead to enough increased runoff from melting glaciers that would fill the gap between decreasing amounts of precipitation and increasing water demand. The study concluded that instead of gambling on nature and global warming to help in avoiding international water conflict, the riparian countries should seek to establish an effective water allocation system for the Syr Darya river basin catchment. (Siegfried *et al*., 2010) Four strategies were identified in reducing the excessive flood loses along the Sarawak River system in Malaysia. These are a new flood map, an early warning system, a relief programme, and more community education. Such measures could help the growing population of Kuching city that is located within the flood prone Sawarak river basin (Mah *et al*., 2011). In the Himalayan region, there is no question that climate change is gradually and powerfully changing the ecological and socioeconomic landscape, particularly in relation to water. Business as usual is not an option. It is imperative to revisit and redesign research agendas, development policies, and management and conservation practices, and develop appropriate technologies.

Hazard mapping would 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. (Eriksson *et al.*, 2009) In the Ganges River Basin, for example, there has long been discussion that the best opportunities to control floods and to augment low-season flows in India and Bangladesh would be investment in river regulation and storage in Nepal (Sadoff and Muller, 2009).

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 difference and increase water availability for irrigation. 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). Irrigation has long been essential to agricultural production in Indonesia. In the 1990s the concepts of integrated water resource management and multi-sector planning were introduced and in major river basins, and new public corporations were created at the basin level to manage bulk water supply allocation, water quality and environmental controls, flood control and water resource infrastructure. Even after decentralization reforms , the central government still retains considerable power, exercising legislative authority and policy-coordination in the water sector, providing technical advice and oversight of lower level administration, setting water tariffs and subsidizing capital costs for engineering works, providing strategic guidance to major basin planning and co-management of large irrigation systems. The provincial level issues licenses and permits for water extraction, and is responsible for water resource management and development projects. The district level provides input to planning and management decisions. At the ground level, water user associations manage irrigation systems, and provide input to district-level planning (Tyler and Fajber, 2009). Engineered approaches to flood protection can leave a community highly vulnerable to catastrophic infrastructure failures, such as those seen in the 2008 Koshi floods in Nepal and India which affected over 3 million people (Sadoff and Muller, 2009). A good example in achieving water security is the case of Singapore, which demonstrated how adopting and aggressively implementing a comprehensive and coordinated approach to achieving – and leveraging beyond – water security. The government has been investing in research and technology, effectively built a robust, diversified and sustainable water supply from four different sources known as the Four National Taps - water from local catchment areas, imported water, reclaimed water known as NEWater and desalinated water (Sadoff and Muller, 2009). The Mekong River Commission established a “Climate Change Adaptation Initiative” (CCAI) in 2009 under its Environment Programme. The CCAI aims to contribute to an economically prosperous, socially just and environmentally sound Mekong River Basin responsive and adapting to climate change induced challenges. The CCAI framework document is based on national studies and puts forward a systematic set of goals, outcomes and indicators and a detailed outline of potential implementing partners. It is based on a legally and institutionally well-developed regime in the lower Mekong basin and has benefitted from well-established modes of interactions between the lower Mekong riparians, sufficient capacities at the MRC Secretariat, continued donor funding as well as considerable international (NGO) attention (Kranz *et al.*, 2010). A case study of climate change policy and practice in Bangladesh pointed out to a mitigation-adaptation-development nexus, using the example of waste-to-compost projects. The projects contribute to mitigation through reducing methane emissions, adaptation through soil improvement in drought-prone areas, and sustainable development, because poverty is exacerbated when climate change reduces the flows of ecosystem services (Venema and Rehman, 2007 in Ayers and Huq, 2009). While combined mitigation and adaptation policy is not a magic bullet for a comprehensive climate policy, synergies, particularly at the project level, can contribute to the sustainable development goals of climate change and are worth exploring (Ayers and Huq, 2009).

Two policy processes were taken into account in Uzbekistan regarding the issue of low water years in agriculture, and integration of ecosystem water needs into water allocation planning. A study concluded that lack and weakness of formal institutions, lack of human and technical capital and inadequate planning and adaptation were main influencing factors in the implementation of measures for the improvement of the water resources management sector. 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 and the lack of vertical integration are possible explanations for the rather low adaptive capacity (Schlüter *et al*., 2010).

Institutionally, Vietnam is not equipped with a strong lead ministry to guide climate adaptation. Webster and McElwee pointed out that while the Central Committee for Flood and Storm Control is experienced in inter-ministerial coordination and local action, and is set up to respond to disasters when/if they happen, the role CCFSCS is not to coordinate ministry actions to reduce vulnerabilities over the long term. The problem is compounded by a general lack of horizontal integration, and there is also little active involvement of strong ministries in climate change adaptation plans. In addition, the scale for adaptation is unclear, because no national mainstream guidelines were formulated on climate change considerations in developmental planning of all localities (2009).

In the absence of an overarching administrative structure, geographic jurisdictions utilizing a common water body may come into conflict without the resolution mechanisms to remedy it. What was intended to be an effective adaptation strategy for some individuals may end up as maladaptive for those not involved in devising the strategy. For example, districts that improve their water resources infrastructure may enjoy access to greater withdrawal volumes that increase output from irrigated croplands. At the same time, it may increase the vulnerability of downstream users who were not involved in the original decision-making and may have limited legal recourse (Barnett and O'Neil, 2010 in D'Agostino and Sovacool, 2011). In the case of Cambodia, the number of irrigated crop area is expected to rise and these coordination issues consequently grow in importance. Maladaptations may also arise from using inaccurate or incomplete impact forecasts. To date, staff and skills shortage remains a problem for Cambodian ministries as does access to current computing technologies (D'Agostino and Sovacool, 2011).

Olson *et al*. concluded in their study on water availability from streamflows in the Zeravshan river that the significant increases in monthly flows in spring and decreases in monthly flow in summer combined with the estimates of future discharges in 50 and 100 years indicate that the glaciers retreated exceeding their transition point. That is, the decreased glacier volume already leads to reduced flow rates (2010).

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 between sub-regions. North Asia is a region of tundra, boreal forests and grasslands, Central and West Asia are dominated by desert and semi-desert ecosystems, and the Tibetan Plateau is covered in a variety of treeless alpine ecosystems. These four sub-regions have relatively low human population densities in most areas 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.

24.4.2.2. Observed Impacts

Temperatures have shown a consistent rise across Asia, with very few exceptions, since 1970, but changes in precipitation have been complex and varied (e.g. Piao *et al*., 2010; Caesar *et al*., 2011; Ni, 2011; Tchebakova *et al*., 2011). In general, observations of biological changes in terrestrial ecosystems attributed to 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 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).

Phenology. The most widely reported impacts of 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 and Katano, 2008; Primack *et al.*, 2009; Fujisawa and Kobayashi, 2010). However, species responses have been idiosyncratic, and regional consistency has tended to decline as the number of records increases, making it difficult to generalize (Sokolov and Gordienko, 2008).

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. Dulamsuren *et al.*, 2010; Sano *et al.*, 2010; Yang *et al.*, 2010; Shishov and Vaganov, 2010). 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). Satellite data can be combined with meteorological data to estimate terrestrial Net Primary Productivity (NPP), with data for the past decade (2000-2009) suggesting decreased NPP in SE Asian rainforests, in Central Asia and at high latitudes in West Asia, but increases over most of the rest of the region (Zhao and Running, 2010).

Changes in the distributions of species and biomes. Also widely reported are changes in species distributions: generally upwards (e.g. Chen *et al.*, 2011; Kharuk *et al.*, 2010 a, b; Moiseev *et al.*, 2010) or polewards (e.g. Tougou *et al.*, 2009) in response to recent warming. Movements of dominant species can then lead to changes in the distributions of the whole biomes. Biome shifts have been reported mostly from the north of the region. Because of the slow rate of biome boundary shifts, long-term monitoring is needed, which in remote and inaccessible areas has been provided since 1978 by broad-swath satellite remote sensing data. The biome boundary position is a result of a dynamic balance between adjacent biomes. The position of the forest-tundra ecotone 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 for soil moisture and light, as well as fires, are also important (Soja *et al.*, 2007; Zeng *et al.*, 2008; Eichler *et al.*, 2011).

Larch-dominated forest occupies about half the area of Siberia. Invasion of dark needle conifers (DNC, Siberian pine, spruce and fir) and birch into the larch habitat for the last three decades has been observed. Siberian pine and spruce have high invasion potential both along the margin and in the centre of the absolute larch dominance zone. This phenomenon could be attributed to precipitation and temperature increases. 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 overstory 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 can presage a shift in competitive balance between these species. It is likely that prevalence of evergreen conifers in areas currently dominated by deciduous Larix species is increasing (Kharuk *et al.*, 2010; Osawa *et al.*, 2009; 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 late 20th century.

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. Larch tree-ring analysis shows a strongly decreasing annual increment since the 1940s (Dulamsuren *et al.*, 2010). Regeneration of Siberian larch decreased as well and is now virtually lacking in the western Khentey larch forests. Reduced regeneration and growth are likely to cause a retreat of the forest at its geographical drought limit.

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. 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. Little Ice Age permafrost 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).

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: 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 has risen by about 0.1 - 0.3°C between 1996 and 2001 (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.*, 2011).

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 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 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 biomes. The current distribution of potential natural 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 and topography, and in some places by fire. In the longer term, therefore, climate change is expected to change this distribution (e.g. Wang *et al.*, 2011). However, the rate at which this change in potential vegetation is realized will be constrained by many factors, including competition from established plants, seed dispersal, rates of soil development, and habitat fragmentation. Climate simulations for Asia strongly suggest that the warming trend will continue, but projections for precipitation are still highly uncertain. In general, the changes in both temperature and precipitation are expected to be greater in the north and west of the region. These will lead to large and relatively predictable changes in the distribution of potential natural ecosystems (Ni, 2011; Wang *et al.*, 2011; Tchebakova *et al.*, 2011), although the transitional stages will be less predictable.

In Northern Asia, 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.*, 2009; 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). 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. Both replacement of summer-green conifers (larch) with evergreen conifers (DNC) and expansion of boreal forest 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, 2010).

The direction of change in steppe is uncertain: one projection is that steppe area will increase by 27% (Tchebakova *et al.*, 2010) while another is that it will decrease by up to 65% (Golubyatnikov and Denisenko, 2007). Increasing aridity may expand the deserts of northern China, and push the steppe to the northeast (Zhang *et al.*, 2011).

The forest regions of East Asia will largely remain forested, but subtropical evergreen forest will expand north into the deciduous forest zone (Wang *et al.*, 2011). Impacts in Central and West Asia will depend critically on the changes in precipitation, which are still highly uncertain. Forest will expand on the more mesic parts of the Tibetan plateau and there will be a general northwestern shift of all vegetation zones (Wang *et al.*, 2011). 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 will 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). An expected increase in the frequency and severity of droughts will very likely interact with non-climate human impacts to increase fire risk (van der Werf *et al.*, 2008).

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). In Asia, permafrost degradation is predicted to spread from the southern and low-altitude margins, advancing northwards and upwards, but rates of change vary greatly between different model projections (Anisimov, 2009; Cheng and Wu, 2007; Eliseev *et al.*, 2009; Riseborough *et al.*, 2008; Romanovsky *et al.*, 2008; 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). If air temperatures continues to increase, this model shows 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). 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 will exceed 1 m (2 m) under the SRES B1 (A1B or A2) scenario in these regions (Eliseev *et al*., 2009). In Western Siberia, the boundary of the permafrost-covered area is projected to move northward 30-80 km by 2020-2025, and 150-200 km by 2050 (FNCRF, 2010).

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 50 years, but more than half of the permafrost may become relict and/or even disappear by 2100 according to modeling results. The likely result of permafrost degradation will 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. Most inland waters (including wetlands) will probably be affected most strongly by changes in rainfall, which is expected to increase in some areas and decrease in others. Increases in water temperature will impact both living organisms and a wide range of temperature-dependent ecological, chemical, and physical processes. Glaciers are important sources for rivers originating in the Himalayas and Qinghai-Tibet plateau, with glacial melting expected to initially increase followed by a long-term decline (Hamilton, 2010; Piao *et al*., 2010). Changes in river flow also 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 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. Extinction of endemic endangered species with limited migration / seed dispersal ability due to climate change is possible (Heller and Zavaleta, 2009).

24.4.2.4. Vulnerabilities to Key Drivers

For much of Asia, increases in aridity, as a result of declining rainfall and/or rising temperatures, are the key concern. Increased aridity is very likely to have severe impacts on both terrestrial and freshwater systems that are already under stress. Even where mean rainfall remains adequate, any increase in drought frequency and/or severity will increase vulnerability to anthropogenic fires. Freshwater systems are particularly vulnerable to increases in the frequency and intensity of extreme events (droughts or floods), even if average conditions are unchanged (Hamilton, 2010). Adverse impacts from rising temperature are also very 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. The biodiversity of isolated tropical, subtropical, and warm-temperate mountains may be particularly vulnerable to warming, because many species already have small geographical ranges that will shrink further under global warming (Liu *et al*., 2010; La Sorte and Jetz, 2011; Noroozi *et al*., 2011; Peh *et al*., 2011).

Climate-driven changes in tundra and forest-tundra biomes can influence indigenous peoples of the North Asia due to their traditional livelihood: nomadic tundra pastoralism, fishing and hunting. Another stress for western arctic North Asia is intensive exploration of vast hydrocarbon deposits in recent decades resulting in the rapid expansion of infrastructure, a large workers inflow and extensive transformation from shrub- to grass- and sedge-dominated tundra. Grazing land withdrawals for petroleum and gas exploration and for sand and gravel quarrying, pasture pollution by trash and petrochemicals, and off-road vehicle traffic in summer, drive the reindeers onto progressively smaller grounds. The growing road and pipeline network create more difficulties for herders along their migration routes, and newly arrived workers increase poaching and fishing pressure in areas around the main gas and oil fields and transport corridors. Frequency and scale of natural and manmade fires have recently increased in tundra and taiga-tundra zones, one of the causes might also be climate warming, especially summer droughts (Kumpula *et al*., 2011; Nuttall *et al*., 2005; Walker *et al*., 2011).

In spite of the fact that estimates of biome shifts rate and value are uncertain, it could have major climatological implications because of decrease in regional albedo, increase in CO_2 absorption, decrease in CH4 emission, and alteration of the hydrological cycle.
Thawing of permafrost can affect residential buildings, pavements, pipelines used to transport petroleum and gas, pump stations and extraction facilities. Ice roads, an important form of transportation for many northern activities may not be passable when permafrost thaws (Kelmelis, 2011; Smith, 2011; Forbes, 2011; FNCRF, 2010).

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 probably be reduced (Dulamsuren *et al.*, 2010). 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.

[Cross-sector issues: To be discussed for later drafts.]

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. Suggested adaptation strategies have general been generic (e.g. reducing non-climate impacts, monitoring climate impacts, maximizing landscape connectivity, making protected area networks robust to future climate scenarios; e.g. Hannah, 2010; Shoo *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). Assisted migration (or 'managed translocation') of genotypes and species is an increasingly common suggestion where adjustments to climate change are constrained by natural rates of seed movement (e.g. Liu *et al.*, 2010; Tchebakova *et al.*, 2011). More generally, climate change scenarios are being increasingly incorporated into all planning exercises.

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

There is a lack of both scientifically well-founded recommendations and programs aimed at development of adaptation plans for forest-tundra ecotone in Asia at a state level (Greenpeace, 2010). Comprehensive monitoring, assessments and projections that can anticipate numerous development scenarios are needed to elaborate a plan for adaptation to cumulative effects of resource development, climate change, and demographic changes that are occurring on North Asia forest-tundra ecotone (Walker *et al.*, 2011).

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) (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 common along temperate and arctic coasts. Asia also supports around 40% of 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). Seagrass beds are also widespread, although less well studied, and Asia supports the majority of the world's seagrass species (Green and Short, 2003). Kelp forests and other seaweed beds are important on temperate coasts (Bolton, 2010). Permafrost and sea-ice influence coastal processes in the far north (Are *et al.*, 2008). Six of the seven living species of sea turtle are found in the region and five species nest on Asian beaches (Spotila, 2004).

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). The only cases where widespread climate impacts can be identified with confidence are with 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, 2010; Krishnan *et al.*, 2011), and on the sparsely populated Arctic coastline, 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.*, 2011).

Thresholds and Irreversible Changes. It has been suggested that the threshold atmospheric CO_2 concentration for coral reef survival is at or below 324 ppm and has already been exceeded (Royal Society, 2009; Hoegh-Guldberg, 2010).

24.4.3.3. Projected Impacts

There is likely to 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 is likely to fall if, as some evidence suggests, tropical marine species are already near their thermal maxima (Cheung *et al.*, 2009, 2010; Neuheimer *et al.*, 2011). Overall, 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, 2010; Burke *et al.*, 2011; Fabricius *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). The impacts of ocean acidification on other organisms are 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 (30-180 cm; Nicholls and Cazenave, 2010) have increased since AR4. The major projected impacts include coastal flooding, increased erosion, and saltwater intrusion into surface and groundwater. Coral reefs can probably 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. Coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea-levels. 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). Sea-level rise may be more significant in the few near-natural deltas, such as that of the Fly River in Papua New Guinea, but changes should be slow enough to permit adaptation in a naturally unstable system.

Cyclones affect most of the Asian coastline, except in the far north, west, and 10° either side of the equator. Natural coastlines are resilient, but large cyclones can have a devastating impact on isolated ecosystem fragments. However, current trends in cyclone frequency and intensity are unclear (IPCC SREX, 2nd order draft). A combination of cyclone intensification and sea-level rise could potentially result in 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).

Sea turtles nesting beaches are likely to be impacted by increased temperature, sea-level rise, and any changes in cyclonic activity, but the capacity of turtle populations to adapt is not well understood (Hawkes *et al.*, 2009; Poloczanska *et al.*, 2009).

In the Asian Arctic, rising sea-levels will interact with projected changes in permafrost and the length of the ice-free season, potentially increasing rates of coastal erosion (Pavlidis *et al.*, 2007; Lantuit *et al.*, 2011). 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.*, 2011). 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 for 0.5 m for 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. This rate will vary across the Asian Arctic coast from 3 to 9 m/year (Pavlidis *et al.*, 2007).

24.4.3.4. Vulnerabilities to Key Drivers

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.

Such industrial infrastructure as sea ports, tanker terminals, oil and gas pipelines and facilities can be affected by sea coast erosion in Asian Arctic. Coastal erosion is threatening critical contaminated sites, with potential for spreading of pollutants (Forbes, 2011).

[Cross-sector issues: To be discussed in a later draft.]

24.4.3.5. Adaptation Options

Coastal defenses such as dykes 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. Taking into account the projected changes in the coastline in the Asian Arctic when new infrastructure and house construction is planned is an adaptation measure to the potential hazard (FNCRF, 2010).

24.4.4. Food Production Systems and Food Security

24.4.4.1. Sub-Regional Diversity

AR4 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.

In addition, there are now more detailed researches impacts to crop production. In AR4, climate change was projected to mainly lead to reduction in yield. New research shows there will be gainers as well. Depending on the regions changes and the crops grown, effects will substantially vary.

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). A study reporting on the correlation between the annual rainfall and the total production and yield of wheat and barley in Jordan showed that the impact of rainfall on the total production was more than its impact on the average yield. In year 1999, the total production and average yield for wheat and barley were the lowest among the years. This could be explained by the low rainfall during this year, which was 30% of the average. These results would reflect the vulnerability of both crops to climatic variations. This was also indicated by the ratios of cultivated to harvested areas (Al-Bakri *et al.*, 2010).

Zhang *et al.* assessed rice yield responses to recent climate change at experiment stations, in counties and in provinces of China for the period of 1981–2005, and concluded that yield at a regional scale indicated a varying climate to yield relationships. In some places, yields were positively regressed with temperature when they were also positively regressed with radiation. However, in others, lower yield with higher temperature was accompanied by positive correlation between yield and rainfall (Zhang *et al.*,2010).

The nomadic herders of Mongolia demonstrate a detailed understanding of weather and climate and provide an account of climatic change that integrates multiple indicators. According to the herders the dust storms and droughts are more frequent and severe, rains are patchier, less effective and delayed. However, their evidence of change is only partly supported (or even contradicted) by meteorological records, larger scale predictions and general circulation models. The bad weather perception by herders has been found to positively correlate to the number of dead cattle. In other words, the years the nomads graded as bad weather years have a high number in dead animals, while the years graded as having good weather have shown a reduced number of total animal deaths (Marin, 2010).

24.4.4.3. Projected Impacts

Production

AR4 mainly dealt with cereal crops (rice, wheat corn). Since then, impacts of climate change have been modeled for additional crops. In semi-arid and arid regions of Western Asia, 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). C3 plants respond with a higher average increment in biomass production than C4 plants. For example, wheat and rice grain yield increased by an average of 12% at ample N and water with elevated CO_2. 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 withy 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 indicated that barley would be more negatively affected by the climate change scenarios 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 are likely to cause wheat yields to decline (by 7% and 24% respectively) in Swat district and 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). Climate change was projected to reduce monsoon sorghum grain yield by 2 to 14% by 2020 with worse yields by 2050 and 2080. 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).

Since AR4, there have been a number of studies on the impacts of climate change to crop productivity in China with varying results. Rice is the most important stable 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. Without the CO_2 fertilization effect, the yield of irrigated rice along the Yangtze River decreases by 14.8%, and the yield of rain-fed rice decreases by 15.2% on average (Shuang-He *et al*., 2011). With CO_2 fertilization effect factored in, the yield of irrigated rice decreases by 3.3% and the yield of rain-fed rice decreases by 4.1% on average. Tao *et al*. (2008) reported similar findings. Without CO_2 fertilization effects, the growing period would shorten with 100% probability; 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 changes of 1, 2, and 3 °C, respectively. However, if CO_2-fertilization effects were included, the rice growing period would also be reduced with 100% probability; across the stations 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. 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 experiment 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 overwhelmed temperature's effect on rice yield variation. Wassman *et al*. (2009a, 2009b) provide the most comprehensive review of climate change impacts and adaptation for rice in the region.

There were also modeling work for other crops in China. In the Huang-Hai Plain, China's most productive wheat growing region, modeling work indicates that winter wheat yields would increase on average by 0.2 Mg ha-1 in the earlier period and by 0.8 Mg ha-1 in the later period due to warmer nighttime temperatures and higher precipitation (Thomson *et al*., 2006). Yields are 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 is greatest.

Liu *et al*. (2010) worked on a wheat-maize cropping system in Huang-Huai-Hai (3H) Plain. Generally, climate change would result to a mean relative yield change (%) (RYC) 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 change of yield with increasing temperatures. 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%). 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 (Chavas *et al*., 2009). Their results indicate that aggregate potential productivity (i.e. if the crop is grown everywhere) with CO_2 fertilization increases 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 declines in all cases ranging from 2.5 to 12%.

Farming systems and crop areas

Since AR 4, 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 as mentioned in AR4.

Climate change threatens the food security of West Asia where majority of draylands are occupied by rangelands (Thomas, 2008). The region has the world's lowest rates 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 are likely to lead to: changes in the 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 increasing aridity 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 can be winners (cereal production in northern and eastern Kazakhstan can benefit from the longer growing season, warmer winters and slight increase in winter precipitation), while others can be losers (particularly western Turkmenistan and Uzbekistan, where frequent droughts will 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 depends on 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 show that there will be a 51% decrease of 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 will be more vulnerable.

In Sri Lanka, various 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) ranges from US$96.4 million (-20%) to US$34,214 million (+72%) depending on the climate scenarios.

In eastern China, there is a study showing 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 and 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 can reduce rice yield by approximately 1-5%. However, another experiment suggests 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 coming decades, due to increases in water demand for non-agricultural uses, 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 demonstrate a detailed understanding of weather and climate. According to the herders, the dust storms and droughts are more frequent and severe, rains are patchier, less effective (‘harder’) and delayed. All of these could affect livestock production in the country.

Future food supply and demand

This section in AR4 was largely based on global models which included Asia. Since then there are now a few quantitative studies on the whole continent and countries. In general, these studies suggest that the risk due to climate change of hunger, food insecurity and livelihood losses will be high.

Rice is a key stable crop in Asia and 90% or more of the world’s production is from Asia. An Asia-wide study revealed that climate change would reduce rice yield over a large portion of the continent (Masutomi *et al*., 2009). The most vulnerable in the 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 likely 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. The impacts of these price changes vary on the source of income. Poverty rates in some non-agricultural household could rise by 20–50% in parts of Asia and falling by significant amounts for agriculture-specialized households elsewhere in the continent.

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. 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 Production and Farming systems and cropping areas 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)/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. These are summarized in Table XX [forthcoming]. There is new information on West and Central Asia. There are also much more crop specific and country specific adaptation options available.

It is noteworthy that farmers have been adapting to climate risks for generations. Indigenous and local adaptation strategies have been documented in the Philippines (Peras *et al*., 2008; Lasco *et al*., 2011). 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 shows 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 are the most important reasons for not adopting drought-related technical measures. It is interesting to note that 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

Sustainable development of Asian countries will be challenged as climate change compounds the pressures that rapid urbanization, industrialization, and economic development have placed on natural resources (IPCC, 2007b). One of the main issues will be the availability of adequate fresh water, which by the 2050s will be a concern for possibly more than 1 billion people. Coastal systems and other low-lying areas in ASEAN countries, more than 170,000 km (ASEAN, undated), are highly vulnerable to rising sea levels as well as to the new frequency and pattern of extreme weather events. The Asian mega-deltas are likely to be particularly affected by climate change (UNISDR, undated). Millions of people, across borders, are likely to be affected by floods, storm surges, coastal erosion, loss of land and resources, saltwater intrusion, and other hazards every year, particularly in the large and heavily populated deltas of Asian region.

Settlements and growth

Asia, being the largest continent of the world in terms of area and population, is both diverse and complex. Population distribution is uneven within Asia. For example, two sub-regions i.e. Eastern Asia and South-Central Asia, account for 80% of the continents population (UNFPA, 2010). 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. Most of the population growth expected in urban areas will be concentrated in the cities and towns of the less developed regions. Asia, in particular, is projected to see its urban population increase by 1.7 billion (UN, 2010) in 2050.

Most Asian countries are witnessing significant development opportunities as well as a myriad of challenges. The rise of Asia will be led by the Peoples Republic of China, India, Indonesia, Japan, Republic of Korea, Malaysia and Thailand. In 2010 these seven economies had a combined GDP of $14.2 trillion (87 % of Asia). By 2050 their share is expected to rise to 90 %. These seven economies alone will account for 45 % of global GDP (ADB, 2011). Climate change will affect all Asian countries. Across all the sub-regions of Asia, poor people tend to live in high-risk areas such as unstable slopes and flood plains, and often cannot afford well-built houses. The poorest people will likely to suffer the most from climate change. If adaptation and disaster risk reduction strategies are not implemented timely, the impact of climate change could set back years of development efforts.

Settlements and climate change

About 59% urban population in Asia live in coastal zones, and this is projected to increase to 70% by 2025 (Balk *et al.*, 2009). Settlements, which are not near the coast but living in unstable slopes or landslide prone areas, faces increased likelihood 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 India and many describe this as a new phenomenon called ‘urban drought’.

The cities of Asia serve as centers of higher education, innovation and technological development. Buildings and transport in cities account for the bulk of energy consumption and carbon emissions (ADB, 2011). Thus, offer opportunities for effectively address both mitigation as well as adaptation challenges. With very high “concentration of people, industrial and cultural activities, cities have potential to address ‘mitigation’ by innovatively strategizing reduction in greenhouse gas (GHG) emissions as well as improve coping mechanisms, disaster warning systems, and social and economic equity, to reduce vulnerability to climate change impacts (adaptation)” (UN-Habitat, 2011).

Depending on the method that is used, GHG emissions from cities could vary between 40 to 70 % (UN-Habitat, 2011). Citing the case of Beijing and Shanghai where industry contributes 43 and 64 % of total emissions, respectively, there is a suggestion that the economic base of a city is an important factor in determining its GHG emissions. Industrial emission in the city of Tokyo is 10 % which is low due to shifting of major industrial activities elsewhere in the region (UN-Habitat, 2011). With the nuclear disaster Japan is experiencing after the March-2011 tsunami, settlements, infrastructure and industries are likely to move swiftly towards renewable, clean and safe energy with an added cushion for climate resiliency. Within the city also, GHG emission may vary across people living under different conditions. For example, "in Mumbai, the per capita emissions for Dharavi, the large, predominantly low-income, high-density, inner-city settlement will be a very small fraction of the per capita emissions of a high-income district in Mumbai where a high proportion of the population commutes to work by car (Satterthwaite, 2008).

24.4.5.2. Observed Impacts

Hanson *et al.* (2011) presented the first estimate of "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, taking into account scenarios of socio-economic and climate changes. The analysis suggests that 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". The bulk of exposed assets in Asia are currently concentrated in Japan.

Seaports as important infrastructure play a vital role in economic development which directly influences industry and human settlements. A survey of port authorities from around the world indicated that sea-level rise was perceived to be an issue of great concern especially in the next century (Becker *et al.*, 2011). There was a 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.

Significant increase was found in the annual mean temperatures during 1974-2002 in large urban and industrial areas in Korea (Chung *et al.*, 2004). The temperature increase was large for large cities and populated areas, while at rural and seashore stations the changes were comparable to the global average. Asia is seeing intense rainy day, prolonged dry days, increased heat-stress - all of which are affecting the built environment, industry and infrastructure at a varying degree in its sub-regions.

Although tourism is largely dependent on climatic and natural resources, uncertainties prevail in predicting tourist flows under scenarios of climate change (Gossling and Hall, 2006). Case study from Israel and Tanzania suggests that "a considerable group of tourists makes travel decisions irrespective of the climate. For example, travel motives might include visiting relatives and friends or the visitation of a World Heritage Site. Climate change may have little influence on such travel decisions, even though weather extremes such as tropical storms might become relevant for this group of tourists. The study also suggests that 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.

24.4.5.3. Projected Impacts

Impacts on human settlements

There are direct and indirect impacts on human settlements and living facilities from climate change. Some impacts are local and some are regional, and some impacts may lead to mutation and tragedy (Lei, 2004). Climate change may cause more extreme weather events and lead to natural environment change, thereby impacting the socio-economic system and affecting living facilities and human settlements. The impacts on human settlements and living facilities include shortage of water resources; growth in health care expenses; effects on seasonal tourism, implications on livelihoods and threat to the physical and mental wellbeing of urban residents.

By the year 2025, 70% of Asia's urban population will live in the coastal ecozone, with majority located in low-elevation coastal zone (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).

Poor people often have limited choice and hence settle in places which are most at risk from local environmental degradation (such as near sanitary landfills, unstable slopes, and low-lying areas), have minimal access to public infrastructure (safe water, sanitation, health, and public transport) and insufficient means of livelihood (working in low-wage informal sector, illegal/unsafe industries having no means of health and safety). These conditions also provide them disproportionate exposure to climate related threats including heat-waves, floods, storms and insufficient, poor quality drinking water.

Asia is still predominantly rural and hence agriculture being the biggest source of livelihood in rural areas, affect rural human settlements, rural industry and rural infrastructure. Climate change hotspots have been identified in selected regions of Asia (Ericksen *et al*., 2011). The implications on human settlements, industry and infrastructure are summarized in Table 24-4.

[INSERT TABLE 24-4 HERE
Table 24-4: Potential impacts of climate change in urban areas (still under preparation).]

Impacts on industry and infrastructure

The influences of tackling climate change on industry include two aspects, one is from direct impacts on industry production from climate change and extreme events and another is from indirect impacts from the restriction for industrial enterprise to implement the mitigate activities (Li, 2008). Climate change may cause serious threat to production safety, for example heavy precipitation events may lead to landsides, debris flows and other geological disasters in mining enterprises (Wu, 2006). Extreme events may damage the infrastructure and increase the costs of industrial enterprise. The probability being affected by extreme events to equipment operation and maintenance in power industry is increase steadily. Extreme events can cause huge damage for grid infrastructure (Arthur Andersen, 2008). Some industrial sector that mainly process indoor (such as textiles, printing, and electronic) may also be affected by climate change. Climate change and extreme events may also have a greater impact on large and medium-sized construction projects.

On the other hand, climate change may have positive impacts on industry. For example, warming particularly in the summer, will stimulate the consumption of beer, cold drinks and other light drinks industry, and increase their economic benefits. The action for addressing climate change may also increase further innovation for new and renewable energy (Chen, 2005). Emission mitigation obligations will restrict development of the industrial sector and increase the cost of businesses; and indirectly cause constraints for economic and social development. However, it can also promote the development and innovation of new technology and industrial upgrading, and to accelerate the development of renewable energy, which can provide new opportunities for industrial sector.

Hanson *et al*. (2011) estimates that for world's large port cities "by the 2070s, total population exposed could grow more than threefold due to the combined effects of sea-level rise, subsidence, population growth and urbanization with asset exposure increasing to more than ten times current levels or approximately 9% of projected global GDP in this period. Exposure is concentrated in a few cities: collectively Asia dominates population exposure now and in the future and also dominates asset exposure by the 2070s. Importantly, even if the environmental or socio-economic changes were smaller than assumed here the underlying trends would remain".

Nicholls *et al*. (2008) reveals that "by the 2070s, the Top Asian cities in terms of population exposure (including all environmental and socioeconomic factors), are Kolkata, Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, and Hai Phòng. 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). The study further calculated exposure to extreme water levels relative to the baseline as represented by current exposure to a 1 in 100 year event and informs that Asia has a significantly higher number of people living under an elevation corresponding to the 1:100 water level, with 65% of the global exposed population" (Nicholls, 2008). Lastly, 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).

24.4.5.4. Vulnerabilities to Key Drivers

Size, growth, structure and density of population are key determinants to GHG emissions and other environmental impacts of cities (UN-Habitat, 2011). Hanson *et al.* (2011) reports that "on the global-scale, population growth, socio-economic growth and urbanization are the most important drivers of the overall increase in exposure particularly in developing countries, as low-lying areas are urbanized. Climate change and subsidence can significantly exacerbate this increase in exposure. Risk-reduction planning and policies at the city scale is critical to address issues raised by the possible growth in exposure.

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.

Perch-Nielsen (2010) presented a "beach tourism vulnerability index on a national level as a new method of looking at the possible effects of climate change on tourism. Of 177 coastal countries worldwide, aggregated results were presented for 51 countries in which tourism is most important and for which full data sets were available. Aggregate results on an annual and national level indicate that, regarding beach tourism, large developing countries might be among the most vulnerable due to high exposure and low adaptive capacity. Small islands states are also vulnerable, especially due to their high sensitivity towards climate change. However, the aggregated index should only be seen as a starting point for a more detailed comparison of individual indicators including local knowledge for the countries of interest". A number of Asian countries were found vulnerable with regard to beach tourism in this study.

Link between migration and climate change is also not very clear despite attention being drawn in this direction in the recent years. Perch-Nielsen *et al.* (2008) explored the "connection between climate change and migration via two mechanisms, sea level rise and floods. In both cases, a connection can be traced and the linkages are made explicit. However, the study also clearly shows that the connection is by no means deterministic but depends on numerous factors relating to the vulnerability of the people and the region in question". UN Habitat (2011) reports that "In 2008, an estimated 20 million individuals were displaced due to sudden-onset natural disasters alone. Projections for future climate change-related displacement average 200 million migrants by 2050."

The climate change impacts on human settlements, industry and infrastructure will not only be due to oft-discussed sea-level rise and extreme weather events. Most basic services such as water supply, sanitation, energy provision, and transportation system disruption mean a lot to local economies "and strip populations of their assets and livelihoods, in some cases leading to mass migration. Such impacts are unlikely to be evenly spread among regions and cities, across sectors of the economy or among socioeconomic groups. Instead, impacts tend to reinforce existing inequalities and, as a result, climate change can disrupt the social fabric of cities and exacerbate poverty" (UN-Habitat, 2011).

24.4.5.5. Adaptation Options

Hunt and Watkiss (2011) reviewed the "academic and 'grey' literature to provide an overview assessment of the state of the art in the quantification and valuation of climate risks at the city-scale and found that the climate risks most frequently addressed in existing studies are associated with sea-level rise, health and water resources while other sectors such as energy, transport, and built infrastructure remain less studied". It further concludes that "while low cost climate down-scaling applications would be useful in future research, the greatest priority (emerging from the literature review) is to develop responses that can work within the high future uncertainty of future climate change, to build resilience and maintain flexibility. This can best be used within the context of established risk management practices".

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". Ranger *et al.* (2011) demonstrates that in Mumbai, "adaptation could significantly reduce future losses; for example, estimates suggest that by improving the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70%; by extending insurance to 100% penetration, the indirect effects of flooding could be almost halved". Klein *et al.* (2007), through portfolio screening of official development assistance for mainstreaming adaptation to climate change, concludes that initially adaptation lacked attention due to "dearth of understanding regarding practical links between poverty reduction and adaptation to climate change, and a perception of climate change adaptation as being limited to technological responses to identified changes in climate variables". It underscores the need for "comprehensive approach to adaptation, that is, for mainstreaming to address a range of stressors and underlying causes of vulnerability, in addition to technological adaptation measures." The concentration of future exposure to sea level rise and storm surge in rapidly growing cities in developing countries in Asia urgently underscores the need to integrate the consideration of climate change into long-term coastal flood risk management and disaster planning, rather on more immediate reactive responses" (Hanson, 2011).

UN-Habitat (2011) reveals that "many governments in developing countries are initiating national studies of the likely impacts of climate change and developing 'National Adaptation Programmes of Action'. But, many give surprisingly little attention to urban areas, considering the importance of urban economies to national economic success and for most countries, to the incomes and livelihoods of much of the population. Thus, it has been suggested that what is needed is city-focused 'City Adaptation Programmes of Action' and local-focused 'Local Adaptation Programmes for Action'". "The local specificity of climate effects has not deterred cities from working together. In recent years, there has been a proliferation of urban networks and partnerships that aim to fill in adaptation knowledge and resource deficits (IIEd, 2011).

Over 50 % of the world's urban population lives in cities with population under 500,000 which signifies that substantial urban growth is happening in smaller urban areas (UN-Habitat, 2011). Prevailing institutionally weaknesses in these smaller urban centers need to be addressed effectively in order to promote climate-sensitive infrastructure development, better preparedness to reduce possible climate induced disaster risks and publicize energy-efficient urban development. In other words, smaller urban areas have better potential to fetch adaptation-mitigation co-benefits.

Adaptation and disaster risk reduction measures need to be made a formal part of development processes and budgets and programmed into relevant sector projects, for example in the design of settlements, infrastructure, coastal zone development, and forest use in order to achieve sustainable land management, avoid hazardous areas, and to ensure the security of critical infrastructure such as hospitals, schools and communications facilities.

- UNISDR and WB are jointly working on mainstreaming disaster risk reduction into ASEAN Development process.
- UNHCR is conducting emergency management training programme, in the form of a cooperative endeavor with the ASEAN Committee on Disaster Management (ACDM) (see previous reference).

- ILO is starting activities towards the development of community infrastructure to reduce impact typhoons in the Philippines, and also in building rural roads in Aceh, Indonesia.
- UNDP together with ILO, FAO and UNEP have started capacity-building activities to adapt to climate change in the Philippines.
- The Joint Programme "Strengthening the Philippines' Institutional Capacity to Adapt to Climate Change" (2008-2012) bring together relevant agencies working on environmental sustainability and adaptation to climate change. The project aims at achieving: i) Climate risk reduction (CRR) mainstreamed into key national & selected local development plans & processes; ii) Enhanced national and local capacity to develop, manage and administer plans, programmes & projects addressing climate change risks; and iii) Coping mechanisms improved through pilot demonstration adaptation projects
- UNDP in Thailand is having a project called "Women Empowerment in Community-based Disaster Risk Management, through Tsunami Experience" in four provinces affected by Tsunami in the South of Thailand. Supported by the UN Foundation and the Coca Cola Company, the project attempts to streamline and optimize procedures for community disaster preparedness by integrating grassroots inputs, particularly women contributions into the planning process. This one-year project is an extension to the UNF and TCCC support during the Tsunami recovery and rehabilitation phase and to provide platform for future work to link community –based disaster risk management to climate change adaptation. The recent tsunami experience has shown strong evidence of women's crucial role during the recovery and rehabilitation phase. The project intends to utilize community organization technique of group and networking process focusing on women, accompanied by a need-based leadership and capacity strengthening programme to enhance women's role. Comprehensive awareness training on women's inputs during tsunami recovery and a right-based approach to women status will be concurrently implemented to improve community traditional perception and social image of women. Prior experience on water resource management will be emulated in target communities with emphasis on women's active participation in Water User Group administration. Women's involvement in natural resource management will give them a platform to gain acceptance among community members. Finally, women will be encouraged to participate in the design and administration of the community based disaster risk management plan for future disaster preparedness through a multi-stakeholder mechanism that involves local administration and grassroots organizations. With the incorporation of women's contribution, the target communities are better prepared to cope with future natural disasters and the impacts of climate changes.
- The joint UNDP-UNEP Poverty Environment Initiative (PEI) is working in Cambodia and Vietnam to enhance adaptive capacity to climate change risks by mainstreaming climate adaptation concerns into national plans, sectoral strategies and the decentralization process.
- Climate Impact and Adaptation in Asian Coastal Cities: ADB is working with the World Bank and the Japanese International Cooperation Agency on the Climate Impact and Adaptation in Asian Coastal Cities initiative to support an analysis of climate change risks and their costs in coastal mega-cities of Asia, including the ASEAN cities of namely Bangkok, Ho Chi Minh, and Manila. Together, these urban areas are home to more than 30 million residents, many of whom face increasing risks from flooding, heat waves, water shortages, and other adverse impacts of climate change. The study includes economic analysis to determine the likely costs associated with these climate-induced phenomena as a means to prioritise adaptation measures.

ADB's Ho Chi Minh Study will develop modelling scenarios using HydroGIS as a tool to quantitatively integrate rainfall, land-use and sea level into water regime scenario for HCMC, and PRECIS regional climate models for impact downscaling, to assess current knowledge and coping strategies for floods, cyclones, and tides, and identify vulnerable infrastructure and communities.

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). 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 large proportion of rural population dependant on agriculture, agriculture has been identified as a key driver of economic growth in the region (World Bank, 2007).

Many parts of Asia are already witnessing new threats to human security, brought about by climate change, in additional to traditional security issues that these regions already face. 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 as well as health. 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. For example, differential vulnerabilities in the agriculture sector and the case of small and marginal rain fed farmers in South Asia (Sivakumar and Stefanski 2011) and rural poor in rangelands of West Asia (Thomas, 2008). A large body of work in the past years has focused on food security concerns and changes in crop yields, productivity and sensitivity to changes in temperature and precipitation (Ohta and Kimura, 2007; Liu *et al.*, 2010) and occurrence of extreme events such as droughts and floods as well as human health.

24.4.6.2. Observed Impacts

Asia is the main affected continent of climate-related disasters, in particular hydrological disasters. Severe floods, flash floods, and landslides have affected several hundred million people and killing thousands in Pakistan, India, Bangladesh, Myanmar, China and North Korea since 2006 (Guha-Sapir *et al.*, 2010;Warraich *et al.*, 2011). Severe storms with hundreds to thousands of deaths and millions affected have hit South and South-East Asia and Taiwan of China (Gua-Sapir *et al.*, 2010; Harris *et al.*, 2008). Epidemics have been reported in the aftermath of floods and storms (Bagchi, 2007; Qin and Zhang, 2009) due to decreased drinking water quality (Bhutta, 2010; Chan and Griffiths, 2010; Harris *et al.*, 2008; Solberg, 2010), invasions of mosquitos (Pawar *et al.*, 2008; Zaki and Shanbag, 2010; Warraich *et al.*, 2011), and exposure to rodent-borne pathogens like hantavirus and Leptospira (Kawaguchi *et al.*, 2008; Majra and Gur, 2009; Shivakumar, 2008; Wuthiekanun *et al.*, 2007; Zhou *et al.*, 2011). Contaminated flood waters in urban environments have caused exposure to pathogens and toxic compounds in e.g. India and Pakistan (Sohan *et al.*, 2008; Warraich *et al.*, 2011). Mental disorders and posttraumatic stress syndromeare frequently observed(Feng *et al.*, 2007; Li *et al.*, 2010; Udomratn, 2008; Wisitwong and McMillan, 2010), in India linked to age and educational level (Kar *et al.*, 2007; Telles *et al.*, 2009). 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). Drought has been associated with increased suicides among Indian farmers (Rao, 2010), and diarrhoea and nutrient deficiencies among children (Arlappa *et al.*, 2011).

Heat in combination with smoke exposure from wildfires after a severe drought in Russia in 2010 caused high mortality and morbidity. Increased temperatures are correlated with deaths and increased hospital admissions in China, in particular for persons with cardiovascular and cardiopulmonary diseases, and the elderly(Guo *et al.*, 2009; Huang *et al.*, 2010; Kan *et al.*, 2007; Qian *et al.*, 2010; Tan *et al.*, 2010; Wong *et al.*, 2010). Correlations between high temperatures, air pollution, and daily mortality and morbidity have been reported from China, Republic of Korea, and Taiwan of China (Lee *et al.*, 2007; Qian *et al.*, 2010; Yi *et al.*, 2010). Linear correlations between temperature rise and mortality have been shown for Delhi (McMichael *et al.*, 2008) and several cities in East Asia and South Korea (Chung *et al.*, 2009; Kim *et al.*, 2006). Heatwaves have been shown to be occupational hazards for outdoor workers, farmers, and construction workers in South Asia, India, and Taiwan of China (Hyatt *et al.*, 2010; Lin and Chan, 2009; Nag *et al.*, 2007). Dust storms are increasing public health concerns in China and South West Asia (Griffin, 2007; Griffin *et al.*, 2007; Kan *et al.*, 2011). Increased temperatures and relative humidity show strong correlations with Mycoplasma pneumonia in Japan (Onozuka *et al.*, 2010), allergic asthma due to fungal spores in Kuwait (Qasem *et al.*, 2008), and with allergic disorders in Turkey (Kurt *et al.*, 2007).

Increased temperature and heavy rainfall show correlation with diarrhoeal outbreaks in Bangladesh (Hashizume *et al.*, 2007a, 2008), India (Majra and Gur, 2009) and Taiwan of China (Chou *et al.*, 2010). A Japanese study has shown linear correlation between gastroenteritis cases and temperature with 7.7% cases increase for every 1°C temperature increase (Onozuka *et al.*, 2010b). Several Chinese studies have shown correlations between temperatures and outbreaks of bacillary dysentery (Huan *et al.*, 2008; Zhang *et al.*, 2007, 2008), and one study showed 10% increase in cases per 1°C rise in max temperature (Zhang and Hiller, 2008).Outbreaks of diarrhoea in Japan were associated with temperature and rainfall depending on socio-economic and sanitary contexts(Hashizume *et al.*, 2007).Outbreaks of systemic Vibrio vulnificus infection show correlation with increased temperatures in Israel (Paz *et al.*, 2007) and Taiwan of China (Kim and Jang, 2010). Higher water temperatures in nutrient coastal waters that trigger algal blooms have been associated with cholera outbreaks in Bangladesh and India (Huq *et al.*, 2005).

Outbreaks of dengue fever have been correlated with a combination of temperatures and rainfall in Thailand (Sriprom *et al.*, 2010) and Taiwan of China (Hsieh and Chen 2009, Shang *et al.*, 2010) and with rainfall patterns in the Philippines (Su, 2008; Nitatpattana *et al.*, 2008). A Singaporean study shows linearity between dengue incidence and temperature and precipitation at a time lag of 5-16 and 5-20 weeks (Hii *et al.*, 2009).A 3-month lag after increased temperature and humidity could explain dengue incidence patterns in southern Taiwan of China (Shen *et al.*, 2010). Japanese encephalitis transmission has been correlated with temperature, precipitation and humidity in China and India (Bi *et al.*, 2007; Murty *et al.*, 2010) and with the monsoon season in Nepal (Bhattachan *et al.*, 2009; Patridge *et al.*, 2007).Several studies from India and Nepal have found correlations between rainfall and malaria incidence (Dahal, 2008; Dev and Dash, 2007; Devi *et al.*, 2006; Laneri *et al.*, 2010). Rainfall and increases in temperature were correlated with malaria re-emergence in central China close to water bodies (Zhou *et al.*, 2010) and with number of malaria cases in Taiwan of China (Kim and Jang, 2010). In particular high night temperatures were associated with malaria outbreaks in China (Zhang and Hiller, 2010). Temperatures could explain the distribution and seasonal activity of malaria mosquitoes in Saudi Arabia (Kheir *et al.*, 2010). The cause of malaria epidemics in an highly malaria endemic area in China could be explained by a model using the mean temperature of the previous month, of the previous two months and the number of cases during the previous month (Xiao *et al.*, 2010).Climate variability is often one of several factors influencing malaria prevalence (Bui *et al.*, 2011, Kiang *et al.*, 2006).Temperature, precipitation, relative humidity and virus-carrying index among rodents are correlated with incidence of rodent-borne hemorrhagic fever with renal syndrome (HFRS) in China (Guan *et al.*, 2009; Yan *et al.*, 2008).

24.4.6.3. Projected Impacts

Extreme climate events are projected to increase in the Asian Region and will further exacerbate public health problems in vulnerable disaster-prone areas. Heatwaves are projected to increase mortality, e.g. in the Gulf countries (Husain and Chaudhary, 2008). Several coastal regions will be affected by sea level rise (Wheeler, 2011), that may cause salt intrusion in drinking water, loss of land, and climate refugees (Rao, 2010; Shahid, 2010c).Food security may be adversely impacted by changes in seasonal rainfall patterns, e.g. in India (Rao, 2010). Milder winter temperatures would decrease the risk of acute myocardial infarction in temperate zones (Wang *et al.*, 2006). Higher temperatures and humidity are projected to increase allergic disorders, e.g. in Turkey (Metintas *et al.*, 2010). Increases in heavy rain and temperature will increase the risk of diarrhoeal diseases. A 1°C rise in max temperature is projected to increase bacillary dysentery cases with 10% in Jinan, China (Zhang *et al.*, 2008). Climate change may cause disease transmitting vectors to become established in new areas in northern and mountainous regions in Asia when seasons become milder and longer, as projected for malaria mosquitos (Fisman, 2007). The risk of malaria is expected to sharply increase in Yemen, decrease in Oman and remain the same in UAE (Husain and Chaudhary, 2008). In India, prolonged malaria seasons are projected in the north (Majra and Gur, 2009). Malaria incidence may increase in northern India but decrease in areas where mean summer temperatures are above 32°C (Garg *et al.*, 2009).Climate-disease models show increased northern distribution of schistosomiasis in China (Kan *et al.*, 2011, Zhou *et al.*, 2008).

There is very sparse published literature on past and projected future impacts of climate change on livelihoods and poverty. In general, the available literature suggest that unmitigated climate change impacts in the future could result in significant impact on the regions prospects for sustained development in terms of income generation, food security and poverty reduction (ADB, 2009). 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). A review study undertaken by the Asian Development Bank has indicated significant economic costs due to climate change impacts mostly on agrarian and related sectors in the East Asia. The negative impacts are pronounced after 2050 due to severe negative impacts on rice production, the principle and staple food crop grown in this region. These negative impacts on agriculture productivity would have significant impact on the aggregated household welfare, livelihoods and poverty in the region (Zhai and Zhuang, 2009).

24.4.6.4. Vulnerabilities to Key Drivers

There are evidences suggesting that agricultural production will be affected by climate change but very few studies that assess the impacts across scales, for example linking drop in production to poverty levels at the regional level, national economic welfare and the global food commodity prices (Hertel *et al.*, 2010). Apart from detrimental impacts of extreme events such as flooding (Douglas, 2009) and droughts on agriculture, food security concerns are also a composite result of changes in water governance regimes (Hanjra and Qureshi, 2010; Lal, 2011), land-use patterns, for example for biofuel production (Tirado *et al.*, 2010a), demographic trends and socio-economic growth (Su *et al.*, 2009; Wei *et al.*, 2009). In Southeast Asia, another 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). Studies indicate that warmer temperatures are likely to expose places to vector-borne diseases such as dengue and malaria. 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 and related human health outcomes (Marques *et al.*, 2010).

24.4.6.5. Adaptation Options

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).Studies from Japan and UAE show the importance of adequate rehydration, cooling and job breaks among outdoor workers to reduce heat stress under increasingly hotter conditions (Joubert *et al.*, 2011; Morioka *et al.*, 2006).To be observed is that increased use of cooling towers may increase the risk of legionellosis outbreak (Lin *et al.*, 2009). Early warning and forecasting outbreak models are being tested for several diseases for use in planning and managing disease prevention and vector control programme. A Bhutanese model forecasts number of malaria cases based on temperatures and previous disease prevalence(Wangdi *et al.*, 2010), and an Iranian early warning model for malaria uses one month's lag of temperature, relative humidity and previous numbers of malaria cases (Haghdoost *et al.*, 2008). Flea index, rodent density, and low rainfall could be used as ecological indicators of plague risk in Vietnam (Pham *et al.*, 2009). A satellite-based early warning system for coastal cholera outbreaks in Bangladesh and India is possible by using remote sensing of chlorophyll concentration (as indicator of algal blooms), sea surface temperature, and rainfall (Constantin de Magny *et al.*, 2008). Temperature has been suggested to be used as predictor of number of cases bacillary dysentery in China (Zhang *et al.*, 2007, 2008).

While there are some practical experiences of adaptation in Asia at the regional, national and local level there are still several financial, biophysical, technical and institutional factors that can act as barriers and/ or pose limits to adaptation. 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 (Su *et al.*, 2009) in this regard. Dependency of the success of deployment, implementation and sustainability of adaptation options on the political economy of a region cannot be undermined. 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 (Janes, 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, 2011).

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).

There is considerable stress in the literature on low cost options and the need for scaling up of the same, 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).

24.4.7. Valuation of Impacts and Adaptation

24.4.7.1. Diversity of Valuation Studies

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 focused on disperse sectors though without comprehensive economic valuation or assessment and 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 Viet Nam reported that many of the impacts from climate change are not in traditional economic sectors, with the result that their valuations are difficult and many aspects are likely to be missed. Furthermore, some of the economic and social valuations, such as loss of life or damage to ecosystem, can be contentious. Without further mitigation or adaptation, the four countries are projected 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 0.6% for that period.

The ADB report also showed 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 is likely to pay off in the future. 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. It was stressed that there are currently great uncertainties associated with the economic aspects of climate change (ADB, 2009). Adaptation cannot entirely remove the projected damage of climate change, and thus must be complemented with global mitigation of CO_2 in order to avoid the greater impact of future climate change (Begum *et al.*, 2011; ADB, 2009; MNRE, 2010).

24.4.7.2. Challenges in Valuation

In order to cope with multiple regional stresses with respect to increasing stresses caused by climate change, land use, political, and socio-economic changes of the past decades, nations need to develop and implement sustainable adaptive strategies that should be appropriate from an environmental perspective, cost-effective from an economical perspective and acceptable from social and cultural perspectives (Lioubimtseva and Henebry, 2009).

While mitigation efforts are essential, literature suggests that work must begin on building understanding of the likely 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; climate science, behavioral science, and legal and moral aspects 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). In practice, cost–benefit analysis, in a broad sense, is likely to be the only framework within which it is meaningful to assess climate change policies (Agrawala and Fankhauser, 2008; Lecocq and Shalizi, 2007; Metroeconomica, 2004). Most other frameworks, such as cost-effectiveness analysis, will only work well when the adaptation policy is the main or single government policy objective. In practice, this is rarely the case (Stage, 2010).

24.5. Adaptation and Mitigation Interactions

There are potential synergies and conflicts in adaptation and mitigation measures in Asia. In general, ecological adaptation measures that increase plant biomass, such as ecosystem protection and reforestation, will contribute to climate mitigation by carbon sequestration. The opposite is not necessarily true, however, since exotic monocultures may fix more carbon than native species mixtures while supporting less biodiversity and contributing less to ecological services. Compromises that favor biodiversity-rich carbon storage that is resilient to future climate change will be necessary (Díaz *et al.*, 2009). The potential for both adaptation and mitigation through forest restoration is greatest in the tropics (Sasaki *et al.*, 2011). At higher latitudes (>45oN) 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 is likely to 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.

Changes in land use, like agroforestry, may provide mitigation-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.

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, 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 non-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 and active transports and less private vehicles could decrease the number of injuries, deaths and 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).

Several mitigation technologies will also have public health benefits, like controlled composting, state-of-the-art incineration, expanded sanitation coverage, and waste water management (Bogner *et al.*, 2008). Replanting trees in many of Asia's rapidly growing cities would increase carbon storage while decreasing the urban heat island effect (Klein *et al.*, 2005) thus improving health. Actions to reduce current environmental 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).

24.6. Implications for Sustainable Development

24.6.1. 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).

Based on the burden sharing and the equity principle, there is necessity to provide new and additional financial resources to meet the agreed full cost incurred by the developing country parties in developing related adaptation policies and measures (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.

24.6.2. 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, acerbated 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).

With natural resource conservation already in crisis, the focus has been on actions 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). There is also 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 needed for some species in fragmented landscapes (Thomas, 2011). More generally, conservationists may need to abandon 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).

24.6.3. Mainstreaming and Institutional Barriers

The imperative for climate change adaptation has been expressed more commonly in calls to "mainstream" it into local, national and international development policies, planning, and activities. While there is no universally accepted definition of mainstreaming, it has been variously defined and described as follows, with integration as the key word (Agrawala and van Aalst, 2005; Persson and Klein, 2008).

The logic is that by implementing mainstreaming initiatives, adaptation to climate change will become part of or will be consistent with other well established programs, particularly sustainable development planning (Adger *et al*., 2007). It will also help reduce the sensitivity of development activities to both current and future climate (Klein *et al*., 2008). Arguably the most effective way to address climate change impacts on the poor is by incorporating adaptation measures into sustainable development and poverty reduction strategies (Klein *et al*., 2007b; Huq *et al*., 2006).

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; Perez and Yohe, 2005). 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; Tearfund, 2006). This is ironic considering that a great majority of developing countries are signatories and active participants to multilateral environmental and development agreements. For example, in the Philippines, the reasons that hinder climate change mainstreaming are the following: national priorities are biased towards more pressing concerns and 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. Projects such as these could provide an entry point in integrating climate change adaptation in the country.

24.7. Research Priorities

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. 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. If current warming projections are accurate, large areas in the Asian tropical lowlands will experience climates in 2100 that have not existed anywhere on Earth for several million years. 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. Boreal forest dynamics will be influenced by complex interactions between rising temperatures and CO_2 concentrations, permafrost thawing, forest fires, and insect outbreaks. Understanding this complexity will require enhanced monitoring of biodiversity and especially of species ranges, improved modeling, and a greater knowledge of species biology.

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

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 need to identify low cost options and the need for scaling up of the same, considering the vast majority of population living below 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 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.

24.8. Case Studies

24.8.1. Transboundary Issues – Mekong River Basin

The lower Mekong River Basin (MRB) covers an area of approximately 606,000 sq km across the countries of Thailand, Lao PDR, Cambodia and Vietnam (Hinkel and Menniken, 2007). More than 60 million people in the densely populated MRB are heavily reliant on natural resources, in particular agriculture and fisheries for their well-being (MRC, 2009; Dugan *et al.*, 2010). Across the MRB 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. Lao PDR) and sea level rise (e.g. Vietnam's Mekong Delta). Agricultural output has been noticeably impacted by these climate related events, for example resulting in rice production loss in Cambodia and Lao PDR (1995 – 2001).

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 (ADB) among others (MRC, 2009). National level adaptation plans have been formulated in all four riparian countries. A commonly shared view on future climate impacts as well as an integrated and co-ordinated adaptation program across the MRB does not exist to date. A range of individual studies that assess future MRB 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 MRB (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 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; and (3) Reduced fish survival, growth and reproductive success (Dugan *et al.*, 2010). To address these vulnerabilities, adaptation needs are focused on improved water management, farming and fishing practices (Johnston *et al.*, 2010; Hoanh *et al.*, 2003) as well as coastal protection. Effective transboundary adaptation planning and management in the future will need to address the following: (1) Creation of a commonly shared 'view' of future climate impacts across MRB countries (MRC, 2009); (2) Stronger co-ordination among adaptation players and sharing of best-practices; (3) Better integration of climate change into the broader policy frameworks of the National Governments (MRC, 2009); and (4) Stronger linkage of transboundary policy recommendations to national climate change plans and policies (Kranz *et al.*, 2010). Currently sub-optimal resource allocation and adaptation gaps for some sectors or geographies most likely exist. A common framework of what constitutes 'successful' adaptation initiatives in the specific MRB context does not exist to date and is currently subject of an ongoing study.

24.8.2. 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 GHG mitigation projects involving the restoration of groundwater levels (Jaenicke, 2010).

24.8.3. 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 the total river runoff to Aral, Balkhash and Issik Kul Lakes, Ob and Tarim rivers (Shults, 1965; Aizen *et al.*, 1995, 1998). All rivers, except the Ob R. discharge water to central Asian arid endorheic basins populated with over 150 million people from Turkmenistan, Afghanistan, Uzbekistan, Tajikistan, Kyrgyzstan, Kazakhstan, Mongolia and Xinjiang, the north-western province of China and Russia. In the last 50 years (1960 -2009), central Asian glaciers lost on average 10% of their area (15% of ice volume).

The rate of glacier recession varies. Accelerated glacier ice melt increases total river runoff in heavy glacierized basins by 8% (Aizen and Aizen, 2011a). The glaciers of Altai-Sayan mountains are located in the northernmost periphery of the Central Asian mountain system at a south edge of the Arctic basin in Siberia (Table 24-5, Figure 24-1). Altai-Sayan glaciers lost 14% area on average. The accelerated glacier recession in the Altai-Sayan was caused mainly by increase of summer air temperatures by 1.03°C and consequent glacier melt for the last 50 years (Surazakov *et al.*, 2011). The glaciers of Pamir mountains elevations reaches 7,700m asl (Muztagata-Kongur glacierized massifs). Pamir glaciers nourish the Amu Dariya River, the major Aral Sea water stream. During the last 50 years, the largest glacier losses (up to 15%) have been observed in western and south-western Pamir and smallest in the central and eastern Pamir (3-5%) (Aizen *et al.*, 2011b). The Fedchenko Glacier in central Pamir is the world's largest alpine glacier outside of the Polar regions (72km long, 714km^2 area, and 900m max ice thickness) retreated 755m between 1958 and 2009 losing only 2km^2. Tien Shan glaciers located at the largest mountain system in central Asia stretching 2,000km from west to east Tien Shan glaciers are the major sources of water for Balkhash and IssikKul lakes, Sir Darýa and Tarim rivers. Summer precipitation decreased by 10% and Tien Shan glaciers loosed 8.5% of their total area in average during the last 50 years. The largest glacier area loss is observed in the northern and western Tien Shan (14.3%) due to decrease of annual precipitation (20 mm) at elevations above 3,000m asl and increased air temperatures by 0.44°C. Smaller glacier recession 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 7,000m asl). Thus, the central Tien Shan and Pamir glaciers have been revealed as more stable glaciers to climatic changes in central Asia. 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) during the last 50 years in Tien Shan (Aizen and Aizen, 2011a).

[INSERT TABLE 24-5 HERE
Table 24-5: Location and major characteristics of central Asia glaciations.]

[INSERT FIGURE 24-1 HERE
Figure 24-1: 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).]

Simulation models forecast that significant glacier degradation begins when ELA is increased by 600 m compared to the end of 20th century (1961-1990) (Aizen *et al.*, 2007; Mitchell *et al.*, 2004). Then, central Asian glacier covered area may shrink by 40% and glacier volume by 60% of the current state. The IPCC scenarios predict, on average, an increase in summer air temperature of 2°C to 8°C (about 4°C) and an increase in magnitude of precipitation of 0.84–1.24 (about 1.1). If air temperature increases to the greatest predicted value, i.e. by 8°C, and precipitation increases to its maximum predicted value, i.e. by 1.24 times the current rate, then the model predicts a 970m increase in ELA and the number of 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 8°C and precipitation decreases to the minimum predicted value, i.e. by 0.84 times the current rate, then current glaciations will disappear. 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 4.2°C higher than modern. Nevertheless, central Asian glaciers were able to survive even during this Thermal Maximum. Thus, for complete glaciers disappearance mean air temperature should be a least 5°C higher than modern (Aizen *et al.*, 2011d).

24.8.4. Is the Aral Sea Dying?

The Aral Sea (Figure 24-2) was a water-abundant sea-lake in Central Asia that was fourth largest (in area) in the world's list of lakes before the 1960s (Letolle, 2008; Kostianoy and Kosarev, 2010). It is located in the large deserts – Karakums and Kyzylkums. Navigation and the fishery (yearly catches of 44,000 tons) were developed here. The deltas of the Amudarya, the major river of Central Asia, and Syrdarya bringing their waters into the Aral Sea were famous for their biodiversity, fishery, muskrat rearing, and reed production. The local population found occupation in the spheres related to the water infrastructure (Nihoul *et al.*, 2002; Zonn *et al.*, 2009).

[INSERT FIGURE 24-2 HERE
Figure 24-2: 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. Comment: The figure can be changed to the most recent one before the final version of the IPCC AR5 will go to print in 2013.]

Since 1960 riverine water resources have been irrationally used for increasing irrigation of agricultural lands and creation of artificial water reservoirs. As a result the Aral Sea water balance was disrupted, and irreversible alterations in the sea regime appeared that later escalated into one of the "largest ecological disasters of the twentieth century" (Letolle, Mainguet, 1993; Glantz, 1999; Micklin and Williams, 1996). During the last 50 years we have observed a progressive degradation of the Aral Sea and its environment. During this time period the sea shrunk in size from 66,100 km^2 (in 1961) to 10,400 km^2 (in 2008); its volume decreased from 1,066 to 110 km^3; the sea level dropped by 24 m (maximum depth of 69 m was observed in 1961); and its salinity (mineralization) rose from 10 to 116 ppt in the Western Large Aral Sea and about 210 ppt in the Eastern Large Aral Sea (Kostianoy and Wiseman, 2004; Zavialov *et al.*, 2005; Kostianoy and Kosarev, 2010).

The ongoing desiccation, shallowing, and salinization of the Aral Sea have resulted in profound changes in its shape and physical, chemical, and biological regime. The Aral Sea lost its economic importance, and the aftermath of its degradation represents a serious threat to the rapidly growing local population in the Aral Sea Basin (from 14 million in 1960 to 45 million in 2006) due to such factors as a lack of fresh water, water quality loss, salinization of soils, dust and salt storms, climate deterioration, and various diseases. (Kostianoy and Kosarev, 2010).

It is generally accepted that the main reason for desiccation of the Aral Sea has been irrational use of Amudarya and Syrdarya waters for development of irrigation of agricultural lands and the filling of artificial water reservoirs. However, regional climate change (rise in air temperature and decrease in atmospheric precipitation) also plays an important role in this process. Estimates of the amount of water precipitated from the atmosphere over the catchment areas of the Amudarya and Syrdarya rivers for the period 1979–2001 revealed a marked decreasing trend for the Amudarya catchment area from 7-8 to 4-5 km^3 per month on average (Nezlin *et al.*, 2004). According to estimates of the IPCC AR4 (IPCC, 2007), the trend of the mean annual air temperature in the Aral region in 1901–2005 was 1.1-1.7ºC /century. Thus, regional climate change significantly influenced the water balance of the Aral Sea in the past 30 years leading to its supplementary desiccation.

By 2011, the main progress made towards saving of the Aral Sea occurred only in Kazakhstan with the construction of the Kokaral dam between the Small Aral Sea and Eastern Large Aral Sea in August 2005. Thus, the Small Aral Sea is now slowly reviving (including small fishery production), while the Large Aral Sea continues to disappear. Since 2010 the area of the former Eastern Large Aral Sea represents a wetland periodically filled with water and partially desiccated in dry season. The Western Large Aral Sea, as a relatively deep and narrow lake, may die slowly without external water supply.

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Table 24-1: The 52 countries/regions in the six sub-regions of Asia.

Sub-region	Countries/regions	
North Asia (2)	• Mongolia	• Russia
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
South East Asia (12)	• Brunei • Indonesia • Lao People's Democratic • Malaysia • Myanmar • Papua New Guinea	• The Philippines • Republic Cambodia • Singapore • Thailand • Timor-leste • Vietnam
South Asia (8)	• Afghanistan • Bangladesh • Bhutan • India	• Maldives • Nepal • Pakistan • Sri Lanka
West Asia (18)	• Armenia • Azerbaijan • Bahrain • Cyprus • Georgia • Iran • Iraq • Israel • Jordan	• Kuwait • Lebanon • Occupied Palestinian Territory • Oman • Qatar • Saudi Arabia • Syria • United Arab Emirates • Yemen
Central Asia (5)	• Kazakhstan • Kyrgyzstan • Tajikistan	• Turkmenistan • Uzbekistan

Table 24-2: Summary of key observed past and present climate trends and variability.

Region	Country	Change in temperature	Change in precipitation	References
N-Asia	Russia and Ukraine	Slight increase in the warm season (1958-1999)	Small upward trends, large inter-annual variations (1958-1999)	Li et al., 2007
	Mongolia (N-/W-Khentey Mountains)	Increase in summer and winter with1.2-4.4 ◦C AMT*increase in 45-69 years (1961-2006)	AP*fluctuatedbetween-100 and +50mm in 45-69 years (1961-2006)	Dulamsuren et al., 2010 *AMT: annual mean temperature, *AP: annual precipitation
C-Asia	General	Steady increase annually and in winter during 20th century	Slight decrease during past 50–60 years in W-part during 20thcentury	Lioubimtseva and Henebry, 2009
C-/S-Asia	General	Significant increases in percentage of warm nights/days and decreases in percentage of cold nights/days (1961–2000)		Klein Tank et al., 2006
N-/C-Asia, parts of S- Asia	General		Wetter in N- and C- Asia, drier in parts of S- Asia since 1970s	Mertz et al., 2009
TP	General	About 1.8 ◦C increase over past 50 years, rate is 0.36 ◦C/decade (1960–2007)	Increase in most regions (1961-2001), especially in E- and C-TP, decreased trend in W- TP	Wang et al., 2008; Xuet al., 2008
W-Asia	Iran	Marked negative trends for cool days/nights, and DTR*,and positive trends for summer/warm days, and tropical nights over most regions during recent decades	Negative trends, in consecutive dry days over most regions, for annual total wet days precipitation for about 2/3 the regions, and in total wet days within half of N- regions during recent decades	Rahimzadeh, 2009 *DTR=diurnal temperature range
E-Asia	General	Marked sub-regional variability (especially part of N- China-Mongolia areas and TP) for RCCI		Xu et al., 2008 *RCCI: Regional Climate Change Index(change in mean and interannual variability of temperature and precipitation averaged over a given area)
	Korea	Increase in winter, seasonal cycle gradually weakened (1979–2008)	Increasing trend for MWET*, no distinct trend for MDRY* and MWET based on duration (1971-2000)	Im et al., 2011; Kim and Roh, 2010 *MWET: maximum duration of consecutive wet days, *MDRY: maximum duration of consecutive dry days
	Japan	Warming trend over 0.3◦C in Japan; above-normal AMT in Japan (0.86◦C in 2010), relative to 1971-2000 ave.; regionally 2.14 ◦C increase(1951-2000) in Okayama, 2.95 ◦C (1901-2000) in Tokyo; warming trend in mean temperature in March and April was from 0.047 to 0.0771°C/yr (1977-2004); seasonally, strongest warming trends in winter and increasing trends in summer	Above-normal AP in Japan in 2010except on the Sea of Japan side of W- Japan, relative to 1971-2000 ave.	Fujibe, 2009; Japan Meteorological Agency, 2011; Schaefer and Domroes, 2009; Fujisawa and Kobayashi, 2010

	China	Decadal AMT increase of 0.22°C in China(1951-2001), of 0.29°C in North(1961-2000); decadal winter increase of 0.36°C in China(1951-2001), of 0.62°C in North (1961-2000) with significant decadal variations (1951-2000) in S-/S-E/C-W China	Significant decadal variations (1951-2000) in S-/S-E/C-W China; positive trends of JJA* total precipitation over S-E and N-W China, and negative trends over C-China and S-W and N-E Asia; this pattern also appears in the fields of summer precipitation days (1978-2002)	Ren et al., 2005; Ren et al., 2008; Zhang et al., 2009; Yao et al., 2008 *JJA: June, July, August (summer)
S-Asia	General	Increase of 0.7°C /century seasonally and annually, increasing tendency of mean Tmax* (2000-2005) in E-Gangetic Plains (Jessore, Bangladesh; Tarahara, Nepal; Rampur, Nepal; Bhairhawa, Nepal; and Varanashi, India)	Rainfall fluctuations largely random over a century	Lal, 2003, cited by Lal, 2011; Kripalani et al., 2001, cited by Lal, 2011;Sharma et al., 2007 *Tmax: maximum temperature
	India	Significant annual mean warming of 0.68°C /century (1880-2000), Significant increases in Tmax and Tmin*over Deccan plateau (1931-2002), significant decreasing trends in N-W Kashmir in summer DTR	Large inter-annual variability of summer monsoon precipitation (2001-2009)	Lal, 2003; Roy and Balling,2005; Preethi et al., 2011 *Tmin: minimum temperature
	Bangladesh	Increasing mean temperatures at a rate of 0.103°C /decade, more warming for winter compared to other seasons	Increases in AP at a rate of 5.53 mm/yr; AP increase in western part; significant increase in mean AP, increase in number of wet months, decrease in dry months in most parts of the country, seasonally significant decrease of dry months in monsoon and pre-monsoon (1958-2007)	Shahid, 2010 a; Shahid; 2010b
	Nepal	Increase in maximum AMT (1977-2000)	Upward trend of amount of AP in the Jhikhu Khola Watershed, Nepal, with this trend mostly in May-Sept periods	Shrestha and Aryal,2011; Gautam et al., 2010
	Pakistan	2.25◦C AMT increase (1947-2005), 0.38◦C decadal increase in mean temperature in Karachi; strong warming trend in UIRB*,particularly for DJF*	Precipitation trends were inconsistent and showed no definite pattern, either increasing or decreasing	Sajjad et al., 2009; Khattak et al., 2011 *UIRB: upper Indus River basin, *DJF: December, January, February
	Sri Lanka	Decadal increase in mean temperature(1869-2007), based on monthly data from Anuradhapura, Kurunegala, Ratnapura, Badulla, Nuwara Eliya and Colombo	Declining trends of decadal mean annual rainfall over 140years	De Costa, 2008
S-E Asia	General		Increase of total accumulated precipitation from 2,000 to 4,000mm (1979-2003)	Lau and Wu, 2007
	Indonesia	No trend for monthly air temperature (1962-1998)[data obtained from IAEA/WMO, 2004]	A common and significant negative trend of accumulated rainfall in the Brantas Catchment Area, East Java, some increase in annual precipitation in Bogor, West Java (1981-1996)	Aldrian and Djamil, 2008; Watanabe et al., 2010
	Philippines			

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

Country/ Region	Key trend	References
Heatwaves(HWs)		
Russia	HW in Moscow that lasted 62 days killed over 10,000 in summer 2010	Sinclair, 2010, cited byOhba et al., 2010; Ohba et al., 2010
Mongolia		
East Asia	In 2010daily high Tmaxand Tminwere recorded across many cities such as Baghdad, Iraq (45.0 °C);Qalya, West Bank (51.4 °C); Doha, Qatar (50.4 °C); and Jeddah, Saudi Arabia (51.7 °C)	Ohba et al., 2010
China	Increasing frequency and severity of regional wet HW events since 1990s;properties of EWME* have strong spatial dependence, with smaller variability over TP, N- China plain and coastal area of S- China, and larger variability over N- China; one of the severest regional wet HW events and regional dry HW events occurred in 2008, lasting 19 days and 41 days, respectively	Ding and Qian, 2011; Wan, 2009 *EWME=extreme warm-month events
Japan	+1.64°C of mean temperature anomalies for JJA, 2010, highest summer temperature on record since 1898 (+2.25°C recorded in August alone was still highest)	Japan Meteorological Agency, 2010a
Korea	20 HWs(1991-2005), with mean annual duration of 9.3 days(longest is 33 days)	Kyselý and Kim, 2009
India	Sharp increase in duration and frequency of hot days and HW conditions, HW which lasted 47 days hit India, killing 250 people	Ganguly, 2011; Ohba et al., 2010
S-E Asia		
W- Asia, S- Asia andS-E Asia coasts, N-E Siberia	Significant increasing regions of warm day-times and nights (1948-2006) but the increasing regions of warm nights are smaller in W- Asia, larger in S-E Asia	Fang et al., 2008, p.71
Mongolia, N- China, Afghanistan and Pakistan, Malaysia	Significant decreasing regions of warm day-times and nights (1948-2006) but the decreasing regions of warm nights are much larger in Mongolia and north China, and significant increasing regions of warm nights during that same period in Malaysia	Fang et al., 2008, p.71
Intense rains/floods		
Russia	In W- Russia, areas of increase in HP days considerably exceed areas of decrease; in E- part, speeds of the increase are lower and those of decrease, higher, than in W-part (1936-2000)	Bogdanova et al., 2010 *HP=heavy precipitation
Korea	More frequent HP anomaly larger than 100 mm/3 months(1954-2001), more frequent summer HP recently, increase in HP days, significant increasing trends for indices measuring HP frequency and intensity (1971-2000), pronounced enhancement of PN80, PPL95, and PX1D in S- parts	Hoet al., 2003; Booet al., 2006 and Imet al., 2008b, cited byIm et al., 2011; Im et al., 2011 *PN80= the number of days with precipitation above 80mm intensity *PPL95= % of total rainfall from events above long-term 95th percentile *PX1D=greatest 10day total precipitation
Japan	Increased HP(1901-2004) mainly in W- Japan and in autumn, significant increase in heavy daily precipitation (□ 200 mm and □ 100 mm) (1901-1999), increase in very intense hourly and six-hourly precipitations (□100 mm/h and □300 mm/6h) during last 28 years	Fujibe et al., 2006; Fujibe, 2008a
China	Increases in extreme (>50mm/day)/heavy (25-50mm/day) precipitation in S-E China; sudden increase in severe floods during past few decades in Poyang Lake;	Yao et al., 2008; Shankman et al., 2006

	all of severest floods since 1950 occurred during or immediately, following El Niño events	
South Asia	More frequent intense rainfall recently in many parts of S- Asia, increase in frequency of extreme floods, increase in flooding frequency in India and Pakistan	Lal, 2011; Mirza, 2011
India	More frequent VHR* events in 1920s, 1930s, 1980s and 1990s; significant increase in VHR frequency after mid-1970s, decreased HP frequency over C-India since 1980s(1951-2000); increasing trend in heavy rainfall activities during monsoon season; on 26thJuly 2005, Mumbai city received 944 mm of rainfall, heaviest rainfall recorded in past 90 years; on 18th August 2008, Kosi River broke through embankment in Bihar State, eastern India and flooded hundreds of villages, displacing over 3 million people	Rajeevan et al., 2008; Yao et al., 2008; Goswami et al., 2006, cited byPreethi et al., 2011; Kshirsagar et al., 2006; Action Aid, 2008 *VHR=very heavy rain (rainfall events equal or greater than 150mm/day)
Sri Lanka	Worst flooding in more than 50 years left a trail of destruction and claimed 150 lives (2003)	Mirza, 2011
S-E Asia	Extreme high (top 10%) precipitation events are occurring more often than before	Lau and Wu, 2007, cited by Chang, 2011
Bangladesh	5 large floods in 1987, 1988, 1998, 2004 and 2007; very high human and economic damage caused by these floods; the category 4 cyclone Sidron15thNovember 2007 affected more than 8.7 million people and claimed 3,295 lives	Mirza, 2011; OCHA,2007
Malaysia	Extremes of annual rainfall in some parts of Peninsular Malaysia (1971-2005) have changes: increasing trends in I95* and I99*, and a significant decrease in N99*, associated with frequency of extremely wet days	Zin et al., 2010 *I95 and I99=extreme wet day intensities at 95% and 99% percentiles *N99=frequency of extreme wet day at 99% percentiles
Droughts		
Russia	In 2010 drought, temperatures in central plains averaged 42°C and sometimes soared above 50°C, leading to significant grain losses and a harvest that came in at about 30 % below original projections	Munslow and O'Dempsey, 2010; Wegren, 2011
Mongolia and China	Increasing episodes of drought in Mongolia and China	Munslow and O'Dempsey, 2010
China	Trends in drought severity, duration, and frequency (1950-2006) , especially in N-E and C-China, suggesting increasing susceptibility to agricultural drought	Wang et al., 2011[in press]
S- Asia		
S-E Asia		
Cyclones/Typhoons		
Japan		
China	Decreasing trend in TC* frequency over most of China except at such locations as low reach of Yangtze River, with the trend especially significant in South, where averaged number of TCs over last 25 years decreased about 1–2/year, relative to first 25 years	Ying, 2011 *TC=tropical cyclone
Philippines	Rise in number of TCs crossing land is most pronounced over Visayas, but no significant trend apparent in number of annual tropical cyclone events in the Philippines' area of jurisdiction	MO, 2009, cited by Espaldon, 2010; Hilario, 2010, cited by Espaldon, 2010; Espaldon, 2010
S-E Asia Sea	Growing duration of the most extreme winds (tropical storms and typhoons) over South-East Asia seas, mainly the South China Sea and the Philippine Sea	Różyński, 2009
Subtropical E- Asia, S-China Sea	Increasing typhoon influence in Subtropical E- Asia and considerable decrease over S-China Sea(1965-2003)	Wu et al., 2005
E- China Sea and Philippine Sea	Significant decrease in frequency of typhoon passage in E- China Sea and Philippine Sea (1980-2001),relative to 1951-1979	Ho et al., 2004
W-N- Pacific	Decreasing tendency in TC number (1959-2006) in northwestern WNP	Chen, 2009

India	Significant decrease in cyclone frequency (1891-1997)	Srivastava et al., 2000, cited byMirza, 2011
Pakistan	In June 2007, the tropical cyclone Yemy in hit the coastal area of Pakistan in Sindh and Baluchistan provinces and dumped huge rains that caused severe flooding, affecting about 2.5 million people and claimed 330 lives	Mirza, 2011
S-E Asia	More intense and frequent storms	Chang, 2011
Bangladesh	Cyclone Sidr struck S-E coast of Bangladesh on November 15, 2007, killing 3,406 people	Paul, 2009
Myanmar	In early May 2008, Cyclone Narg is hit S-coasts of Myanmar, killing tens of thousands of people and left hundreds of thousands homeless	Lateef, 2009

Table 24-4: Potential impacts of climate change in urban areas (still under preparation).

	Climate change thresholds and major implications	**Possible implications on human settlements, industry and Infrastructure**
1	Length of growing period declines by 5% or more across a broad area of the tropics, including heavily cropped areas of the Indo-Ganetic Plains, and Southeast Asia.	**Human settlement:** Reduction in agricultural yield/rural livelihood opportunities may lead to migration (as decline in growing period is more likely in lower region, and hence deficit in crop production or increase in poverty and hunger. However, in the upper region where production is usually lesser will have increase in food production, and hence surplus food). **Industry:** change in agriculture production will lead to change in crop type, and hence change in diet. Changes in production systems will need industrial relocation because of change in manpower, raw food product availability, etc. **Infrastructure:** migration/Resettlement may lead to conflict among new comers and local inhabitants. There will be increased burdens on medical care facilities, existing houses, water supply, sanitary system, transportation system (road, railways).
2	Length of growing period flips to less than 120 days in a number of locations across the tropics, notably in India. This is a critical threshold for a number of crops as well as rangeland vegetation.	
3	Reliable crop growing days decrease to critical levels below which cropping might become too risky to pursue as a major livelihood strategy in a large number of places across the global tropics, including the Indo-Ganetic Plains.	
4	High temperature stress (above 30:C) will be widespread in north and south India and Southeast Asia. During the primary growing season high temperature stress will be a problem for different areas.	
5	Much of the tropics already experiences highly variable rainfall, above the median of 21% for cropped areas. Thus any increase in this variability will make agriculture riskier.	
6	Reduced rainfall per rain event can be compared to the current drought risk map.	

Table 24-5: 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)
45°-54°N; 84°–103°E	1,562	2,340	2.8	2.1-4.5	0.057
Pamir mountains					
36°-40°N; 66°-76°E	13,424	11,671	4.6	3.4-7.7	no data
Tien Shan mountains					
39°-46°N; 69°-95°E	13,196	10,925	4.4	2.8-7.4	no data

Figure 24-1: 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).

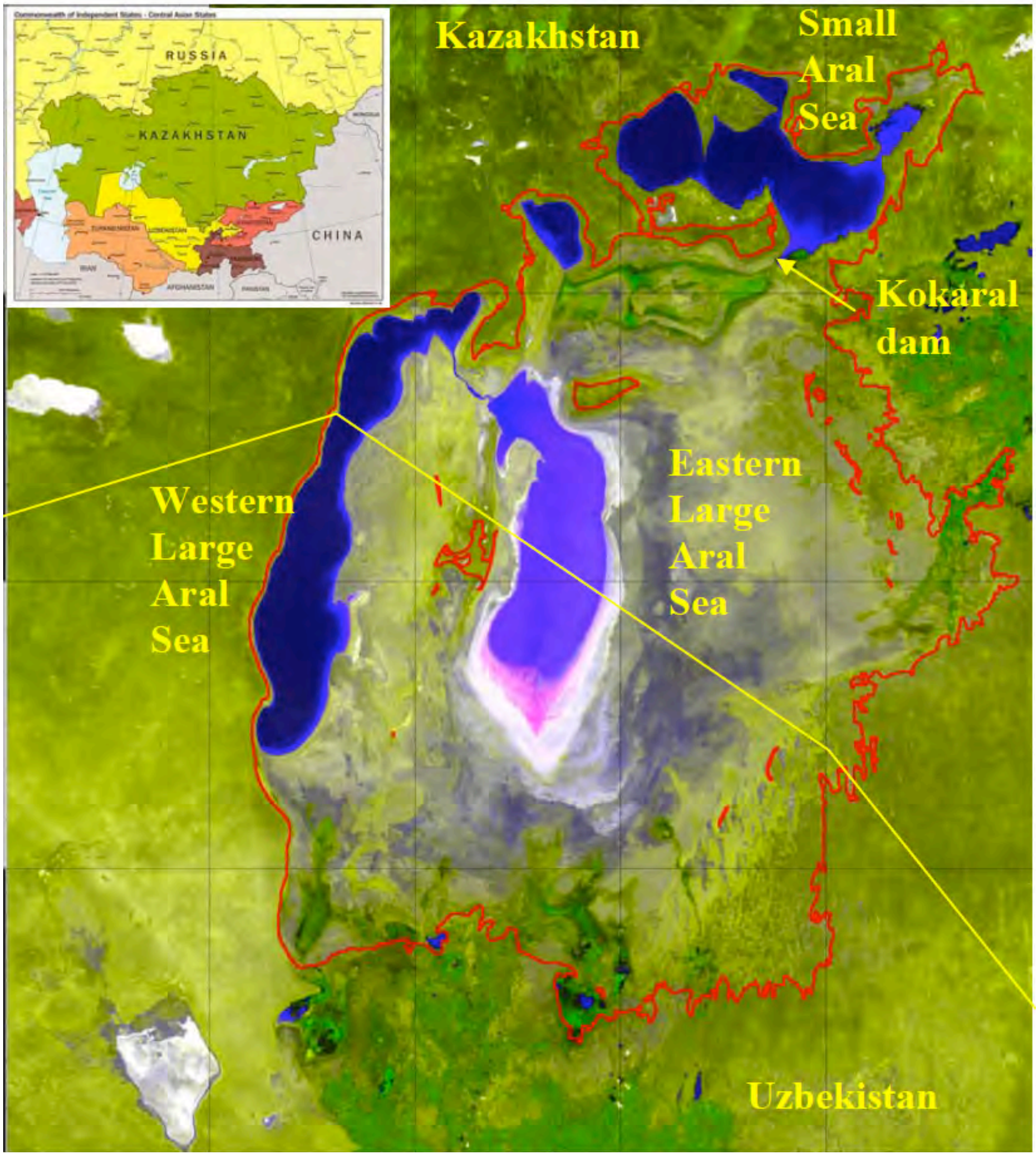

Figure 24-2: The MODIS-Terra satellite image of the Aral Sea on 18 August 2008. Image courtesy by D.M. Soloviev, Marine Hydrophysical Institute, Sevastopol, Ukraine, basing on the data provided by the LAADS Web, NASA-Goddard Space Flight Center (http://ladsweb.nascom.nasa.gov/). Red line shows the Aral Sea coastline in 1960. Yellow line shows the border between Kazakhstan and Uzbekistan. [Comment: the figure can be changed to the most recent one before the final version of the IPCC AR5 will go to print in 2013.]