IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 10 - Asia

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Executive Summary

Based upon recent scientific findings particularly those since the publication of TAR, the key highlights on the impacts, vulnerability and adaptation to climate change in Asia are summarized:

- There is increasing evidence that a distinct and significant warming trend has been noted in most parts of Asia over the past decade. Moreover, annual mean precipitation at a number of observing stations in Asia is reported to be decreasing continuously since 1970s; this decrease has become significant since 1990s. [**10.2.2**]
- There is evidence of prominent increases in the intensity and/or frequency of many of the extreme weather events such as heat waves, tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, snow avalanches, thunderstorms, and severe dust storms on regional scales throughout 1990s and beyond. [**10.2.2**]
- In recent years, the potential crop yield in most countries of Asia has exhibited a declining trend likely due to rising temperatures. The retreat of glaciers in highlands and permafrost thawing in Boreal Asia have been reportedly unprecedented; climate induced diseases and heat stress in central, East, South and Southeast Asia are more frequent; observed changes in terrestrial and marine ecosystems have become more pronounced. [**10.2.4**]
- Continuing emissions of greenhouse gases would result in significant changes in mean climate and its intra-seasonal and inter-annual variability in Asia by the end of 21st century (***high confidence***). An increase in sea surface temperature would also lead to sea level rise, more intense cyclonic storms, higher storm surges and an enhanced risk of disasters along the coastal regions of East, South, and Southeast Asia (***high confidence***). [**10.3**]
- Projected surface warming and shifts in rainfall in most countries of Asia will induce substantial decline in agricultural productivity (***medium confidence***) as a consequence of thermal stress and more severe droughts and floods apart from soil degradation, coastal inundation and salt water intrusion due to sea level rise (in addition to increasing scarcity of arable lands). The net cereal production in South Asia is projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change projections (***medium confidence***). [**10.4.1**]
- Climate change has the potential to exacerbate water resource stresses in most regions of Asia. Freshwater availability in Central, South, East and Southeast Asia is expected to be highly vulnerable to projected climate change and could adversely affect more than a billion people in Asia by 2050s (***high confidence***). Increases in temperature are expected to result in more rapid recession of Himalayan glaciers (***medium confidence***). More sustainable water use based on improvements in water use efficiency and marked changes in irrigation sector would be needed. [**10.4.2**]
- Overexploitation of offshore and inland fisheries in most countries of East, South and Southeast Asia threatens fishery resources today. Changes in currents, water temperature, salinity, strength of upwelling and mixing layer thickness in the West Pacific and North Indian Oceans expected due to climate change and sea level rise will exacerbate the already declining fish productivity in Asia (***high confidence***). Coastal inundation has the potential to damage the Asian aquaculture industry (***high confidence***). [**10.4.3**]
- Climate change would adversely affect human health in Asia. Increase in endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts is expected in East, South and Southeast Asia (***high confidence***). Increase in coastal water temperature would exacerbate the abundance and/or toxicity of cholera in South Asia. [**10.4.5**]
- Climate change would also exacerbate threats to biodiversity resulting from land use/cover change and population pressure in most parts of Asia. Increased risk of extinction for many flora and fauna species in Asia is likely as a result of the synergistic effects of climate change and habitat fragmentation (***medium confidence***). Threats to ecological stability of wetlands including mangroves, and coral reefs around Asia would also increase. [**10.4.3, 10.4.4**]
- Exploitation of natural resources associated with rapid urbanization, industrialization, and

economic development in most developing countries of Asia has led to increasing air and water pollution, land degradation, and other environmental problems that placed enormous pressure on urban infrastructure, human well being, cultural integrity, and socioeconomic settings. These multiple stresses will be compounded further due to climate change. [**10.4.6, 10.5.6**]

- Mainstreaming policies that reduce pressure on natural resources and improve management of environmental risks through integration of indigenous knowledge and technological advances in national development initiatives will enhance the adaptive capacity and coping mechanisms in developing countries of Asia to reduce their vulnerability to climate change. [**10.7.1**]
- Development of innovative solutions and adaptive strategies that deliver long term, sustainable livelihood for the developing countries of Asia are crucial. The development of improved bioenergy systems that have been identified as important means of achieving sustainable rural development in East, South and Southeast Asia have significant potential to contribute to climate change mitigation. [**10.7.2**]
- The inclusion of sector specific climate proofing concept in the design and implementation of national development initiatives in most countries in Asia can help reduce their vulnerability to climate change. [**10.7.2**]

10.1 Summary of knowledge assessed in the TAR

10.1.1 Climate change impacts in Asia

The TAR (IPCC, 2001) re-iterated that while many systems and policies in Asia are not well adjusted even to today's climate and climate variability, continuing anthropogenic emissions of greenhouse gases are likely to result in significant changes in mean climate and its intraseasonal and interannual variability.

Extreme weather events in Asia were reported to provide evidence of increases in the intensity or frequency on regional scales throughout the 20th century. The TAR predicted that the area-averaged annual mean warming would be about 3°C in the decade of the 2050s and about 5°C in the decade of the 2080s over the land regions of Asia as a result of future increases in atmospheric concentration of greenhouse gases (IPCC, 2001). The rise in surface air temperature was projected to be most pronounced over boreal Asia in all seasons.

In general, an enhanced hydrological cycle and an increase in area-averaged annual mean rainfall over Asia were projected in the TAR. The TAR suggested that the increase in annual and winter mean precipitation would be highest in boreal Asia; as a consequence, the annual runoff of major Siberian Rivers would increase significantly. A decline in summer precipitation was likely over the central parts of arid and semi-arid Asia—leading to expansion of deserts and periodic severe water stress conditions. Increased rainfall intensity, particularly during the summer monsoon, could increase flood-prone areas in temperate and tropical Asia.

10.1.2 Vulnerability and adaptive strategies

The TAR reported that water and agriculture sectors are likely to be most sensitive to climate change-induced impacts in Asia. Agricultural productivity in Asia is likely to suffer severe losses because of high temperature, severe drought, flood conditions, and soil degradation. Forest ecosystems in boreal Asia would suffer from floods and increased volume of runoff associated with melting of permafrost regions. The processes of permafrost degradation resulting from global warming strengthen the vulnerability of all relevant climate-dependent sectors affecting the economy in high-latitude Asia. Countries in temperate and tropical Asia are likely to have increased exposure to extreme events, including forest die-back and increased fire risk, typhoons and tropical storms, floods and landslide, and severe vector-borne diseases. The stresses of climate change are likely to disrupt the ecology of mountain and highland systems in Asia. Glacial melt also is expected to increase under changed climate conditions. Sea level rise would cause large-scale inundation along the vast Asian coastline and recession of flat sandy beaches. The ecological stability of mangroves and coral reefs around Asia would be put at risk.

The TAR highlighted that increase in income levels, education, and technical skills and improvements in public food distribution, disaster preparedness and management, and health care systems through sustainable and equitable development in developing countries of Asia should substantially enhance social capital and reduce the vulnerability of these countries to climate change. Specific adaptation strategies for countries in the Asian region were identified in the relevant sectors. Food security, disaster preparedness and management, soil conservation, and human health sectors were identified as crucial for countries in Asia, particularly those with large populations. These countries must develop and implement incremental adaptation strategies and policies based on characteristics of system vulnerability such as resilience, critical thresholds, and coping ranges to

exploit "no regret" measures and "win-win" options. Adaptations for human health essentially involved improving the health care system in many Asian countries. Adaptations to deal with sea-level rise, potentially more intense cyclones, and threats to ecosystems and biodiversity were recommended for high priority action in temperate and tropical Asian countries. It was suggested that the design of an appropriate adaptation program in any Asian country must be based on comparison of damages avoided with costs of adaptation.

Subsequent to publication of the TAR, some advances in our ability to better understand the likely future state of social, economic, and environmental factors controlling the emission and concentration of greenhouse gases and aerosols that alter the radiative forcings of climate have been made. Further analysis of observed historical and current state of climatological state for several countries in the region has been reported which provide new knowledge on the current trends in climate variability and change including the extreme weather events and their impacts. Details on future projections of climatic and environmental changes on finer scales also are now better understood. This chapter presents an update on the vulnerability and impacts of observed and projected climate change on various sectors and regions in Asia, examines how projected changes in climate could affect social, environmental, and economic sectors and identifies sector specific adaptation strategies for countries in the Asian region.

10.2 Current sensitivity and vulnerability

10.2.1 Asia: Regional characteristics

Asia is the most populous of the continents. Its total population in 2002 is reported to be about 3,902 million of which almost 61% is rural and almost 38.5% lives within 100 km of the coast. The coastline of Asia is 283,188 km long (Duedall *et al.*, 2005).

Based on the climate scenarios generated by IPCC WGI, the Asian continent has been divided into six subregions, namely, North Asia, Central Asia, Tibetan Plateau, East Asia, South Asia and Southeast Asia as illustrated in Fig. 10.1 below.

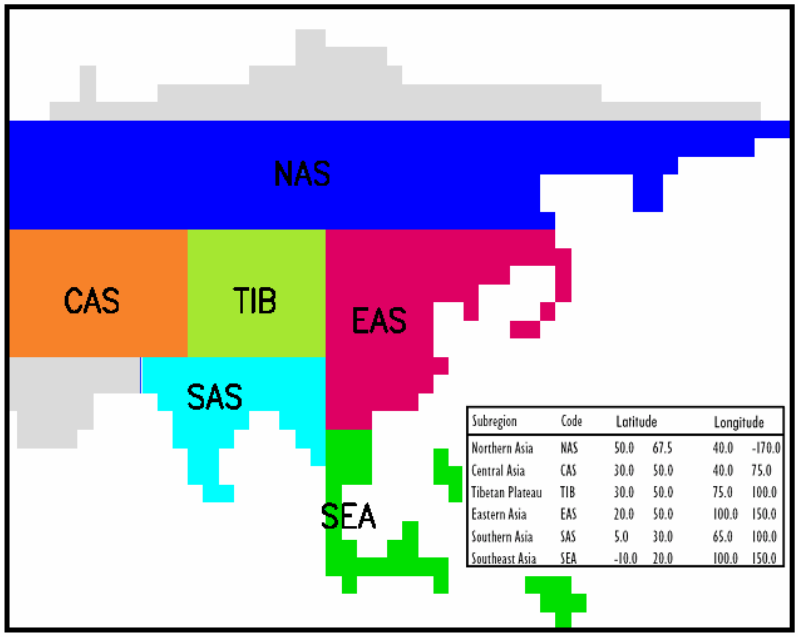

Fig. 10.1: *Asia and its subregions as used in generating the climate change projections for SRES emission scenarios based on seven A-O GCM experiments*

*North Asia***,** located in Boreal climatic zone is the coldest region of the northern hemisphere in winter (ACIA, 2004). Three Siberian rivers—the Ob, the Yenissey, and the Lena—contribute about 65.3% of total runoff from all rivers of the Arctic basin (ACIA, 2004). One of the world's largest and oldest (about 25-30 million years) lakes, Baikal, located in this region contains as much as 23000 km^3 of freshwaters hold nearly 20% of the world surface freshwater resources (Izrael *et al.*, 2000). *Central Asia* includes 21 countries of predominantly arid and semi-arid region. Although the relief is mostly low, there are several peaks of 7,500 m or more in the Hindu Kush and Tian Shan mountain ranges; the lowest point in this region is the Dead Sea (-395 m). Many of the countries in this region are landlocked. *Tibetan Plateau* can be divided into three major parts, the east, north and south. The eastern part is forest region, occupying approximately one-fourth of the land. Natural forests run the entire breadth and length of this part of Tibet. The northern part is open grassland – it occupies approximately half of Tibet. The southern and central part is agricultural region, occupying about one-fourth of Tibet's land area. *East Asia* stretches in the east-west direction to about 5,000 km and in the north-south to about 3,000 km. Much of the natural forests in the region have long been destroyed. Broad plains have been cultivated and irrigated, and natural grasslands have been used for animal husbandry for centuries. *South Asia* is physiographically diverse and ecologically rich in natural and crop-related biodiversity. Although the present population of the region is principally rural, the region includes 5 of the 20 mega cities of which population is more than 10 million in the world (UN-HABITAT, 2004). Agriculture is the main industry in several countries of this region and is predominantly influenced by the monsoons. *Southeast Asia* is characterized by tropical rainforest, monsoon climates with high and constant rainfall, heavily leached soils, and diverse ethnic groups.

Table 10.1 lists the total population, gross domestic product, total land area and land area classified under cropland, forest cover, annual internal water resources, and annual production of cereals, as well as per capita availability of fish and seafood in most of the countries of Asia (WRI, 2003; FAO, 2004a, b, c; World Bank, 2005).

Table 10.1: *Key information on socio-economics of some of Asian countries (WRI, 2003; FAO, 2004a, b and c; World Bank, 2005)*

Country	Mid-2004 population (thousands)	2004 GDP per capita(US$ 2001)	Land Area (10^3 ha)	Arable & Permanent Crops Land, 2002(10^3 ha)	Arable land (1000 ha)(FAO 1998-2002)	Total Forest Area, 2000 (10^3 ha)	Percentage of forest cover (FAO, 2000)	Natural RWR, 2002a (m^3 per person)	Water resources: total renewable per capita (actual) (m3/inhab/yr)*	Average Production of Cereals, 1999-2001 (10^3 t)	Annual Sea Food, Avg. 1997-99 (per capita kg)
- Afghanistan	24926	x	65,209	8,054	7910	1,351	2.1	2,790	2835	3,257	x
- Armenia	3748	556	2,980	560	495	351	12.4	2,778	3427	301	0.5
- Azerbaijan	8447	688	8,660	2,009	1783	1,094	13.1	3,716	3649	1,528	0.9
- Bangladesh	137480	350	14,400	8,429	8019	1,334	10.2	8,444	8418	39,002	10.2
- Bhutan	966	644	4,700	165	145	3,016	64.2	43,214	43379	159	x
- Cambodia	14482	278	18,104	3,807	3700	9,335	52.9	34,561	34476	4,197	12
- China	1313309	911	959,805	153,956	142621	163,480	17.5	2,186	2172	422,218	24.5
- Georgia	5074	594	6,970	1,064	799	2,988	43.7	12,149	12233	554	1.3
- India	1081229	462	328,726	170,115	161715	64,113	21.6	1,822	1807	234,313	4.7
- Indonesia	222611	695	190,457	33,700	20500	104,986	58	13,046	13070	58,954	19
- Iran	69788	1767	164,820	17,088	15020	7,299	4.5	1,900	2020	12,990	4.4
- Iraq	x	x	43,832	6,090	5750	799	1.8	3,111	3077	1,408	1.5
- Israel	x	x	2,214	424	338	132	6.4	265	265	197	23.4
- Japan	127778	32601	37,789	4,762	4418	24,081	64	3,372	3373	12,450	65.4

Country	Mid-2004 population (thousands)	2004 GDP per capita(US$ 2001)	Land Area (10^3 ha)	Arable & Permanent Crops Land, 2002(10^3 ha)	Arable land (1000 ha)(FAO 1998-2002)	Total Forest Area, 2000 (10^3 ha)	Percentage of forest cover (FAO, 2000)	Natural RWR, 2002a (m^3 per person)	Water resources: total renewable per capita (actual) (m3/inhab/yr)*	Average Production of Cereals, 1999-2001 (10^3 t)	Annual Sea Food, Avg. 1997-99 (per capita kg)
- Jordan	x	x	8,921	4,762	295	86	1	169	165	50	5.1
- Kazakhstan	15403	1503	272,490	21,671	21535	12,148	4.5	6,839	7086	14,049	1.9
- Korea, DPR	22776	x	12,054	2,700	2500	8,210	68.2	3,415	3422	3,550	9.4
- Korea, Republic	48199	8917	9,926	1,877	1684	6,248	63.3	1,471	1470	7,559	47.3
- Kuwait	x	x	1,782	15	13	5	0.3	10	8	3	12.1
- Kyrgyzstan	5208	308	19,990	1,411	1345	1,003	5.2	4,078	4062	1,657	0.7
- Laos	5787	326	23,680	1,001	920	12,561	54.4	60,318	60327	2,279	10
- Lebanon	x	x	1,040	313	170	36	3.5	1,220	1226	95	8
- Malaysia	25493	3699	32,975	7,585	1800	19,292	58.7	25,178	24202	2,212	57
- Mongolia	2630	433	156,650	1,200	1198	10,645	6.8	13,451	13599	156	0.1
- Myanmar	50101	162	67,658	10,611	9862	34,419	52.3	21,358	21403	21,322	16
- Nepal	x	x	14,718	3,294	3200	3,900	27.3	8,703	8542	6,874	1.1
- Oman	x	x	30,950	81	38	1	0	364	356	5	x
- Pakistan	157315	415	79,610	22,120	21448	2,361	3.1	2,812	1485	28,682	2.5
- Philippines	81408	912	30,000	10,700	5700	5,789	19.4	6,093	6096	16,917	29.6
- Russia Federation	142397	2141	1,707,540	125,300	123465	851,392	50.4	31,354	31283	67,270	1.7
- Saudi Arabia	x	x	214,969	3,794	3600	1,504	0.7	111	102	2,293	7.6
- Singapore	4261	20733	68	2	1	2	3.3	x	143	x	x
- Sri Lanka	19218	849	6,561	1,916	916	1,940	30	2,592	2644	2,901	21.2
- Syrian Arab Republic	x	x	18,518	5,421	4593	461	2.5	1,541	1511	3,990	1.8
- Tajikistan	6298	169	14,310	1,057	930	400	2.8	2,587	2579	383	0.1
- Thailand	63763	1874	51,312	19,367	15867	14,762	28.9	6,371	6591	29,647	28.2
- Turkey	72320	2230	77,482	28,523	25938	10,225	13.3	3,344	3037	28,829	8
-Turkmenistan	4940	1097	48,810	1,915	1850	3,755	8	5,015	5156	1,358	1.7
United Arab Emirates	x	x	8,360	266	75	321	3.8	56	51	0	25.9
- Uzbekistan	26479	450	44,740	4,827	4484	1,969	4.8	1,968	1961	3,907	0.5
- Viet Nam	82481	411	33,169	8,895	6700	9,819	30.2	11,109	11102	33,909	18.1

10.2.2 Observed climate trends, variability and extreme events

Past and present climate trends and variability in Asia are generally characterized by increasing surface air temperature which is more pronounced during winter than in summer. Increasing trend has been observed across the six sub-regions of Asia. The observed increases in some parts of Asia during recent decades ranged between less than 1 to 3°C per century. Increases in surface temperature are most pronounced in the North Asia (TNCRF, 2002; Savelieva, *et al.*, 2000; Climate Change in Russia, 2003; Gruza & Rankova, 2004).

Interseasonal, interannual and spatial variability in rainfall trend has been observed during the past few decades all across Asia. Decreasing trends in annual mean rainfall are observed in Russia,

Northeast and North China, coastal belts and arid plains of Pakistan, along east coast of India, Indonesia, Philippines and some areas in Japan. Annual mean rainfall exhibits increasing trends in western China, Changjiang River and southeastern coast of China, Arabian Peninsula, Bangladesh and along the western coasts of the Philippines. Table 10.2 lists some details on observed characteristics in surface air temperature and rainfall in Asian sub-regions.

Table 10.2: *Summary of key observed past and present climate trends and variability*

Region	Country	Change in Temperature	Change in Precipitation	References
North Asia	Russia	2 to 3°C rise in past 90 years, more pronounced in spring & winter	Highly variable, decrease during 1951-95, increasing in last decade	Savelieva, *et al*., 2000; Climate Change in Russia, 2003; Gruza & Rankova, 2004
	Mongolia	1.6°C rise in last 60 years, most pronounced in winter	5.5 mm/yr decrease in summer and 3.6 mm/yr on yearly basis	Natragdorj *et al*., 2005; Batima *et al*., 2005a
Central Asia		1-2°C rise per century, no change during 1900-96	No clear trend during 1900-96 except 200% increase in Arabian Peninsula	Peterson *et al.*, 2002
	Northwest China	0.7°C increase from 1961-86 to 1987-2000	22%-33% increase	Shi *et al*., 2002
Tibetan Plateau		0.16 and 0.32°C per decade increase in annual and winter, respectively	Generally increasing in northeastern region	Liu and Chen, 2001; Yao *et al*., 2000; Cai *et al*., 2003; Liu *et al*., 1998; Zhao *et al*., 2004; Du and Ma, 2004
East Asia	China	Warming during last 50 years, more pronounced in winter than summer, rate of increase more pronounced in minimum than in maximum temperature	Annual rain decreased in past decade in Northeast, North China, increase in Western China, Changjiang River and southeastern coast	Hu *et al*., 2003; Zhai *et al*., 1999; Zhai and Pan, 2003
	Japan	~1.0°C rise in 20th century, 2 to 3°C rise in large cities	No significant trend in the 20th century although fluctuations increased	Japan Meteorological Agency, 2005; Ichikawa, 2004;
	Korea	0.23°C rise in annual mean per decade, increased diurnal range	More frequent heavy rain in recent years	Jung *et al*., 2002; Ho *et al*., 2003
South Asia	India	0.68°C increase per century, increasing decadal mean annual, warming pronounced during post monsoon and winter	Increase in extreme rains in northwest during summer monsoon in recent decades, lower no. of rainy days along east coasts	Lal, 2003; Lal *et al*., 2001; Lal *et al*., 1996; Kripalani *et al*., 1996; Singh and Sontakke, 2002
	Nepal	0.09°C per year in Himalayas and 0.04°C in Terai region, more in winter		Bhadra, 2002; Shrestha, 2004
	Pakistan	0.6 to 1.0°C rise in mean temperature in coastal areas since early 1900s	10 to15% decrease in coastal belt and hyper arid plains, increase in summer and winter precipitation over the last 40 years in northern Pakistan	Farooq and Khan, 2004
	Bangladesh		Decadal rain anomalies above	Mirza and Dixit, 1997; Mirza, 2002

Region	Country	Change in Temperature	Change in Precipitation	References
			long term averages since 1960s	
	Sri Lanka	0.016°C increase per year between 1961-90over entire country, 2°C increase per year in central highlands	Increase trend in February and decrease trend in June	Chandrapala and Fernando, 1995; Chandrapala, 1996
SE Asia	General	0.1-0.3°C rise /decade between 1951-2000		Manton *et al*., 2001
	Indonesia		Decreased in south, increased in north	Boer and Faqih, 2004
	Philippines	Increase in mean annual, maximum and minimum, increase of 0.14°C between 1971-2000	Increase in annual rain beginning in 1980s and in number of rainy days in 1990s, increase in onset variability	Cruz *et al*., 2005, PAGASA, 2001,

10.2.3 Observed changes in extreme climatic events

New evidences on recent trends in the intensity and frequency of extreme weather events in Asia over the last century and into the 21st century are discussed below and summarized in Table 10.3 below.

Table 10.3: *Summary of observed changes in extreme events and severe climate anomalies*

Country/Region	Key Trend	Reference
Heat Waves		
Russia	Heat waves broke past 22-year record in May 2005	
Mongolia	Number of heat wave duration has increased by 8-18 days in last 40 years; Cold wave duration shortened by 13.3 days.	Batima *et al*., 2005a
China	Increase in frequency of short heat wave in recent decade, increasing warmer days and nights in recent decades	Zhai *et al*., 1999; Zhai and Pan, 2003
Japan	Increasing incidences of daily maximum temperature >35°C, decreasing extremely low temperature, in July 2004 more than 600 cases of heat stroke due to high temperature	Kawahara and Yamazaki, 1999
Korea	Increasing frequency of extreme maximum temperature with higher values in 1980s and 90s, decrease in frequency of low temperature 1958-2001	Choi *et al*., 2004; Ryoo *et al*., 2004
India	Frequency of hot days and multiple-day heat wave has increased in past century; Increase in deaths due to heat stress in recent years.	De and Mukhopahyay, 1998; Lal, 2003
Southeast Asia	Increase in hot days and warm nights and decrease in cold days and nights between 1961 and 1998	Manton *et al*., 2001; Tran Viet Lien, 2002; Tran Viet Lien *et al*., 2005; Cruz *et al*., 2005
Intense Rains and Floods		
Russia	Increase heavy rains in western Russia and decrease in Siberia, increase in number of days with more than 10mm rain, 50 to 70% increase in runoff of Siberia	Gruza *et al*., 1999; Gruza and Rankova, 2004; Izrael and Anokhin, 2001; Ruosteenoja *et al*., 2003
China	Increasing frequency of extreme rains in western and southern parts including Changjiang river, and decrease in northern regions, more floods in Changjiang river in past decade, more frequent floods in Northeast China since 1990s, more intense summer rains in East China, severe flood in 1999, 7-fold increase in frequency of floods since 1950s	Zhai and Pan, 2003; Zhai, 2004, Zhai *et al.*, 1999; Ding and Pan, 2002

Country/Region	Key Trend	Reference
Japan	Increasing frequency of extreme rains in past 100 years attributed to frontal systems and typhoons, serious flood in 2004 due to heavy rains brought by 10 typhoons; during 1961-2000 increase in maximum rains observed from 120 stations	Kajiwara *et al*., 2003; Isobe, 2002; Kawahara & Yamazaki 1999; Kanai *et al*., 2004
South Asia	Serious and recurrent floods in Bangladesh, Nepal and Northeastern states of India during 2002, 2003 and 2004; A record 944 mm of rainfall in Mumbai, India on 26-27 July 2005 led to loss of over 1000 lives with loss of more than US$250 millions. May 17, 2003 floods in southern province of Sri Lanka were triggered by 730 mm rain	Regional Met. Office, India Meteorological Department, Mumbai; Department of Meteorology, Sri Lanka, 2003
Southeast Asia	Increased occurrence of extreme rains causing flash floods in Vietnam, landslides and floods in 1990 and 2004 in the Philippines and floods in Cambodia in 2000	FAO, 2004a; Tran Viet Lien *et al*., 2005; Cruz *et al*., 2005; FAO/WFP, 2000; Environment News Service, 2002
Droughts		
Russia	Decreased rain and increased temperature by 1°C caused droughts, 27 major droughts in 20th century and 4 between 1972-81	Golubev and Dronin, 2003; Izrael and Sirotenko,2003
Mongolia	Increased droughts in recent years, droughts in 1999-2002 affected 70% of country	Natsagdorj *et al*., 2005; Batima, 2003
China	Increase in area affected by drought has exceeded 6.7 M ha since 2000 in Beijing, Hebei Province, Shanxi Province, Inner Mongolia and North China, increase dust storms affected area	Zhou, 2003; Chen *et al*., 2001, Yoshino, 2000,2002
South Asia	50% of droughts associated with El Niño; Consecutive droughts in 1999 and 2000 in Pakistan and Northwest India led to decline in water tables, consecutive droughts in 2000 and 2002 caused crop failures, mass starvation and affected ~11 million people in Orissa	Webster *et al*., 1998, Lal, 2003
Southeast Asia	Droughts normally associated with ENSO years in Myanmar, Laos, Philippines, Indonesia and Vietnam, droughts in 1997/98 caused massive crop failures and water shortages, and forest fires in various parts of Philippines, Laos and Indonesia	Duong Lien Chau, 2000; PAGASA, 2001; Kelly *et al*., 2000; Glantz, 2001
Cyclones/ Typhoons		
Philippines	Average of 20 cyclones cross the Philippine Area of Responsibility with only 8-9 land fall each year, number of severe cyclones increased from 2.8 per year in 1970-89 to 4.2 per year in 1990-2003	PAGASA, 2001
China	Number and intensity of strong cyclones increased since 1950s, 21 extreme storm surges between 1950 to 2004 of which 14 occurred during 1986-2004	Fan and Li, 2005
South Asia	Frequency of monsoon depressions and cyclones formation in Bay of Bengal and Arabian Sea on the decline since 1970 but intensity on increase causing worst floods in India in terms of damages to life and property	Lal, 2001; Lal, 2003
Cambodia, Vietnam	Tropical storm "Linda" seriously affected agriculture and fishery in Vietnam and Cambodia with damages in billions of dollars	
Japan	Number of tropical storms has two peaks, one in mid 60's and another in early 90's, average after 1990 often lower than historical average	Japan Meteorological Agency, 2005

10.2.3.1 Heat waves

Significantly longer heat wave duration has been observed in many countries of Asia as indicated by pronounced warming trends and several cases of severe heat waves (Batima *et al*., 2005, Zhai *et al*.,

1999; Zhai *et al.*, 2003, De *et al.*, 1998; Lal, 2003, Kawahara *et al.*, 1999, Choi *et al*., 2004; Ryoo *et al*., 2004, Tran Viet Lien, 2002; Tran Viet Lien *et al*., 2005; Cruz *et al*., 2005).

10.2.3.2 Intense precipitation events and floods

Several recent studies have reported increasing frequency in occurrence of more intense rainfall events in many parts of Asia while the number of rainy days and total annual amount of precipitation has decreased in general. At some locations such as Tokyo, though, frequency of intense rainfall has exhibited a decreasing tendency due to decline in the hourly maximum rain in recent years (Kanai *et al.*, 2004). More frequent heavy rains are noted in Siberia (Gruza *et al.*, 1999; Izrael *et al.*, 2001; Ruosteenoja *et al.*, 2003; Gruza *et al.*, 2004), western and southern China including Changjiang River (Zhai *et al.*, 1999; Zhai a *et al.*, 2003; Zhai, 2004), Japan (Kajiwara *et al.*, 2003), Korea (Min *et al.*, 2003), India, Nepal and Bangladesh (Lal, 2003; Tran Viet Lien *et al.*, 2005). Intense rainfall events in recent years have led to more severe flooding episodes, landslides, and debris and mud flows that affect vast low lying areas in Asia including the 31 million hectares of flood-prone areas in South and Southeast Asia (Mirza, 2002; FAO, 2004a). In Southeast Asia and South Pacific, the frequency of extreme rainfall events have declined in most stations and that there has been a weak decline in average intensity of 4 highest events each year (Manton, *et al.*, 2001).

10.2.3.3 Intensity and frequency of droughts

The rise in temperature particularly during the summer and normally drier months, and decrease in precipitation are commonly related to the increasing frequency and intensity of droughts in several parts of Asia including Russia (Meshcherskaya *et al.*, 1990). There are also evidences that most droughts are related to ENSO such as those observed in Pakistan, Bangladesh and India (Webster *et al*. 1998) and in the Philippines (PAGASA, 2001).The intensity of droughts appears to have also increased in terms of the aerial extent and cost of damages as reported in a number of studies in Mongolia, China, India and several countries in Southeast Asia (Duong, 2000; PAGASA, 2001; Manton *et al.*, 2001; Natsagdorj *et al.*, 2005; Lal, 2002, 2003; Batima, 2003). Evidences indicating increase in the magnitude and duration of ENSO, however, remain inconclusive as of this report.

10.2.3.4 Intensity and frequency of cyclones/typhoons

Recent studies indicate that the frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades (Fan *et al.*, 2005). In contrast, cyclones originating from the Bay of Bengal and Arabian Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). In both cases, the damages caused by intense cyclones have risen significantly with enhanced threats to the affected countries particularly India, China, Philippines, Japan, Vietnam and Cambodia, Iran and Tibetan Plateau where build up of high risk areas have increased over the years (PAGASA, 2001; GCOS, 2005**;** ABI, 2005).

10.2.4 Impacts of observed changes in climate trends, variability and extreme events

10.2.4.1 Agriculture and food production

The increasing pressure of changes in climate and its variability would make it more difficult than it is already to step up the agricultural production to meet the growing demands in Russia. Increasing surface air temperature along with increasing intensity and frequency of El Niño, and reduction in number of rainy days have heightened the water stress in many agricultural areas in China lowering the production of wheat especially in the Changjiang Valley, the yield of pasture areas in Qiaghai

Province and the southern part of Gansu Province and corn production in Central China (Tao *et al.*, 2003a; Jin *et al.*, 2001; Tao *et al.*, 2004). Rice and wheat production in the Indo-Gangetic plains of South Asia which increased in the 1970s and 1980s have in recent decade stagnated attributed to the rising (minimum) temperatures during the growing season, the resistance to weedicides, and decrease in soil productivities that appeared in large areas under rice-wheat sequence (Agarwal *et al.*, 2000). In Sri Lanka, 30 cm of soil has been eroded from upland tea plantations over the years while in the lowland tea plantation production has been adversely affected by soil erosion and increased soil moisture deficit brought about by increase in temperature and droughts (Wijeratne, 1996).

10.2.4.2 Hydrology and water resources

Changes in water withdrawals due to continuing population growth, economic activity and expansion of irrigation has led to an intensification of pressure on available water resources in most of the currently severely stressed river basins in Asia. Two key processes that have impacted the hydrology and water resources in Asia in the recent decades are (a) Thawing of permafrost and degradation of frozen soils and (b) melting and retreat of glaciers.

Many cities and human settlements are located in the permafrost regions of North Asia where significant economic and development activities are limited by permafrost and to certain extent threatened by permafrost recession (Osterkamp *et al.*, 2000; Jorgenson *et al.*, 2001; Izrael *et al.*, 2002; Fedorov *et al.*, 2003; Gavriliev *et al.*, 2003; Melnikov *et al.*, 2003; Tumerbaatar, 2003; ACIA, 2004). As permafrost thaws, it jeopardizes both man-made structures and natural features (Izrael *et al.*, 2001). Thawing permafrost on mountain slopes due to significant rise in air temperature in recent years (see Table 10.4 below) has led to frequent landslides (Nelson, 2003).

Table 10.4: *Recent trends in permafrost temperatures measured at different locations (modified from Romanovsky et al., 2002)*

Country	Region	Permafrost temperature change/trends	Reference
Russia	East Siberia (1.6-3.2 m), 1960-1992	+0.03°C/year	Romanovsky *et al.*, 2001
	North of West Siberia (10 m), 1980-1990	+0.3 to +0.7°C	Pavlov, 1994
	European North of Russia, continuous permafrost zone (6 m), 1973-1992	+1.6 to +2.8°C	Pavlov, 1994
	European North of Russia, discontinuous permafrost zone (6 m), 1970-1995	up to +1.2°C	Oberman and Mazhitova, 2001
Asia/China	Qinghai-Tibet Plateau (1970s-90s)	+0.1 to +0.3°C	Huijin *et al.*, 2000
Asia/Kazakstan	Northern Tian Shan (1973-2003)	+0.2° to +0.6°C	Marchenko, 2002
Asia/Mongolia	Khentei and Khangai Mountains, Lake Hovsgol (1973-2003)	+0.3° to +0.6°C	Sharkhuu, 2003

The thickness of frozen soil in Tibet has decreased by 4 to 5 m while the water level in lakes has risen. The thinning of permafrost along the Qinghai-Tibetan Highway has accelerated by engineering

activity in the area (Wang *et al.*, 2004b). Significant permafrost degradation has been observed in China since 1970s as is evident from the increase in thawing depth from only 50 to 70 cm in the past to almost 100 cm in the 1990s while the soil temperature in the upper 20 cm layer has risen by 0.8^{o}C. The forest ecosystem such as spruce-fir forest which depends on the frozen soil has significantly degenerated since 1980s (Guo *et al.*, 2001).

Melting of glaciers in Asia contribute substantially to the freshwater supplies in the region. In drier parts of Asia, wasting glaciers account for over 10% of fresh water supplies (Fitzharris, 1996; Meier, 1998). Glaciers in Asia are melting faster in recent years. Substantial melting of glaciers has been reported in Central Asia, Western Mongolia and Northwest China in recent decades. There are over 8400 glaciers in Tajikistan with total area of about 6% of the territory of the Republic and provide about 25% of the water in Tajikistan rivers (Meshcherskaya, 1990). Observations suggest that since 1908 for 1986 the Zerafshan glacier has highly degraded and receded by more than 1 km since 1908. The volume of ice at the lower boundary of Abramov glacier is also reported to have continously decreased in recent decades. The glaciers on the Tibetan Plateau have also retreated rapidly since the 1980s (*see sub-section 10.6.2 below*). The magnitude of the glacial retreat is the largest at the south and east margins of the Plateau (Pu *et al.*, 2004). Foremost among the impacts of rapid melting of glaciers are the increase in glacial runoff and increased frequency of glacial lake outburst causing mudflows and avalanches such as observed in the Himalayan region (Bhadra, 2002). Recent study in northern Pakistan, however, suggests that glaciers in the Indus Valley region may be expanding due to increases in winter precipitation over western Himalayas during the past 40 years (Archer and Fowler, 2004).

In parts of China, rise in temperature and decreases in precipitation along with increasing water use have also caused water shortages leading to betrunking of rivers and drying up of lakes (Li *et al.*, 2000). In India, Pakistan, Nepal and Bangladesh, water shortages have been attributed to rapid urbanization and industrialization, population growth along with inefficient water use and are aggravated by changing climate and its adverse impacts on demand, supply and water quality (Siddiqi, 2005). In arid Central Asia changes in climate and its variability will continue to challenge the ability of countries in the region to meet the growing demands for water (UNEP, 2002). Decreasing precipitation and increasing temperature commonly associated with ENSO have been reported to increase water shortage particularly in parts of Asia where water resources are already under stress from growing water demands and inefficiencies in water use.

10.2.4.3 Oceans and coastal zones

Global warming and sea level rise in the coastal zone of Boreal Asia has influenced sea-ice formation and decay, thermo-abrasion process, permafrost and the time of river freeze up and break-up in recent decades (Leont'yev, 2004; ACIA, 2004). The monsoonal Asia coast is a high-risk cyclone-prone area with ~42% tropical cyclones of world's total (Ali, 1999). The most dangerous situation occurs when a severe cyclone with heavy precipitation lands on the river delta during the spring tide in a flood season. The superimposed extreme climatic and non climatic events together produce enormous coastal flooding, resulting in serious economic loss and numerous fatalities (Yang, 2000; Li *et al*., 2004a). Coastal erosion and wetland loss occur locally in the monsoon Asia coast. Wetlands in the major river deltas have been significantly altered in recent years due to large scale sedimentation, land use conversion, logging and human settlement (Liu *et al*., 1998; Lu, 2003). Coastal erosion in Asia has led to loss of lands at rates dependent on varying regional tectonic activities, sediment supply and sea level rise (Du, 1997; Sin, 2000).

Saltwater intrusion in estuaries due to decreasing river runoff can be pushed 10-20 km further inland by the rising sea level (Huang *et al.*, 2000; Shen *et al*., 2003; Yin *et al*., 2003; IUCN, 2003; Thanh *et*

al., 2004) and can be aggravated by dam construction (REFERENCE).. Saltwater from the Bay of Bengal is reported to have penetrated 100 km or more inland along tributary channels during the dry season (Allison *et al*., 2003). Severe droughts and unregulated groundwater withdrawal has also resulted in seawater intrusion in the coastal plains of China (Han *et al*., 1999 ; Ding *et al*., 2004).

Nearly 50% of world's Coral reefs are located in the shallow waters of Asia stretching from Red Sea and Indian Ocean to South China Sea and west Pacific Ocean (Spalding *et al*., 2001). Coral reefs (and mangroves) are ecologically important systems with highly concentrated biological activities of species that are especially valuable for maintaining biodiversity and/or resource productivity (Clark, 1996). Southeast Asia has both the largest area of coral reefs and the highest marine biodiversity in the world. It occupies an area of about 100,000 km^2 of coral reefs (nearly 34% of the world total) and contains over 600 of the almost 800 coral species. The Southeast Asia coastline also contains 51 of the world's 70 mangrove species, and 23 of the 50 sea grass species. The total annual benefit of sustainable coral reef fisheries across Southeast Asia is estimated to be US$2.4 billion (Burke *et al*., 2002). Over 34% of coral reefs of South, Southeast and East Asia were lost by the year 1998 (Wilkinson, 2000). About 16% of reef loss was attributed to anthropogenic factors, and 18% resulted from coral bleaching event associated with the 1997-98 El Niño event. Significant bleaching of Coral Reef in Okinawa islands, Japan (Ministry of the Environment and Japanese Coral Reef Society, 2004) and in maritime areas in Guangxi Province and Hainan Province of China has also been reported in recent years in spite of conservation efforts (Wilkinson, 2002; Yamano *et al*., 2004). In the Philippines 46% decrease in live coral cover resulted from bleaching during the 1997-98 ENSO events (Arceo *et al*., 2001).

About 41% of the world's mangroves are found in South and Southeast Asia. Most of theses mangroves have been degraded through clearing, pollution, urbanization and conversion to ponds (Zafar, 2005). Reports on destruction of mangroves due to climate change related factors such as reduction of freshwater flows and saltwater intrusion are limited to the mangroves of Indus Delta (IUCN, 2003; Tablez *et al.*, 2003).

Approximately one third of the mangroves in Malaysia were lost during the second half of the 20^{th} century (Zafar, 2005). Much of the mangrove forests in Singapore have been reclaimed for urban development (Zafar, 2005). Vietnam has lost many of its mangroves due to excessive pesticide use (Zafar, 2005). There are also reports on destruction of mangroves due to climatic factors such as reduction of freshwater flows and related processes like salt water intrusion in Indus delta (IUCN, 2003; Tablez *et al*., 2003).

10.2.4.4 Natural ecosystems

There are reports of more intense and widespread forest fires in recent years in Asia (Shoigu, 2004). Wild fires in Russia contribute to more than half the amount of vegetation destroyed with the burnt areas in the forest exceeding 4.8 times those cut industrially. Annually, from 12000 to 38000 wild fires strike the protected Siberian forests affecting 0.5 to 3 million hectares (Vorobyov, 2004). As a consequence of 17% decline in spring precipitation and rise in surface temperature by 1.5^0C during the last 60 years, the frequency and aerial extent of the forest and steppe fires in Mongolia have significantly increased over a period of 50 years. The economic loss caused by these forest fires has multiplied more than 100 times during the period of 1981-2001 (Erdnethuya, 2003). Forests in Southeast Asia particularly degraded forests are under increasing risk of fires due to human activities and exacerbated by excessive dryness during prolonged dry season usually associated with ENSO. The 1997/98 ENSO event in Indonesia triggered forest and brush fires in 9.7 million hectares, with serious domestic and trans-boundary pollution consequences. Thousands of hectares of second

growth and logged-over forests were also burned in the Philippines during the 1997-98 ENSO events (Glantz, 2001; PAGASA, 2001).

With the gradual reduction in rainfall during the growing season for grass, aridity in Central Asia has increased in recent years, reducing growth of grasslands and increasing bareness of the ground surface. Increasing bareness has led to increased reflection of solar radiation, such that more soil moisture is evaporated and the ground has become increasingly drier in a feedback process, thus adding to the acceleration of grassland degradation (Zhang *et al*., 2003). Many desert organisms in the region are already near their limits of temperature tolerance, and some species may not be able to persist under hotter conditions. In some areas like northern China, human actions have become more influential than climate in inducing desertification (Chen *et al.*, 2001).

Wetlands in the Northeast China are being threatened by warmer climate in the recent decades. The precipitation decline in most areas of Sanjiang Plain during 1995 to 1999 resulted in drying up of wetlands and severe degradation of ecosystems. The recurrent droughts from 1999 to 2001 as well as the building of upriver reservoir and improper use of groundwater have led to drying up of the Momoge Wetland located in the Songnen Plain (Pan *et al*., 2003).

10.2.4.5 Biodiversity

Biodiversity in Asia is being lost as a result of development activities and land degradation (especially overgrazing and deforestation), marine pollution, over fishing, hunting, climate change and the overuse of freshwater (UNEP, 2002). In central arid Asia biodiversity is threatened by rapid changes in land use, extensive but poorly managed irrigation, more intensive use of rangelands, medicinal and food plant collection, construction of dams, and fuel wood collection. In South and Southeast Asia, agricultural expansion has caused serious damages to biodiversity. Loss of biodiversity has also resulted from the degradation of many natural flood plains in Asia due to habitat alteration, flow and flood control, species invasion, introduction of pest, diseases and weeds and pollution (Gopal, 2004).

Information on biodiversity loss in Asia due to climate change remains limited to few countries. In East Asia, the plant and animal species are reported to be moving to higher latitude and altitude as a consequence of observed climate change in recent years. The flowering date of the Japanese cherry (*Prunus yedoensis*) is reported to be 5 days earlier now than 50 years ago (Ichikawa, 2004). A decrease in alpine flora has been reported in Hokkaido, the north island in Japan (Kudo *et al*., 2004) and other high mountains (Wada *et al*., 2004) while distribution of southern broad-leaved evergreen trees such as the Chinese Evergreen Oak (*Quercus myrsinifolia*) in Japan has expanded. Nagasakiageha butterfly (*Papilio memnon thunbergii*), the northern border for which has been Kyushu and Shikoku Islands, appeared in Mie Prefecture in the 1990s, but have shifted to Tokyo area (Yoshio *et al*., 1998 & 2001; Oda *et al*., 2001;). Flowering of Japanese Apricot (*Prunus mume*), Japanese cherry (*Prunus yedoensis Matsum*.), Japanese rhododendron (*Rhododendron kaempferi*), Japanese wisteria (*Wisteria floribunda*), and Japanese hydrangea (*Hydrangea macrophylla Seringe*) and the leaf unfolding of Japanese ginkgo (*Ginkgo biloba L.*) was found to be highly sensitive to changes in daily temperature.

10.2.4.6 Human Health

The heat wave related deaths in Indian state of Andhra Pradesh, Orissa and elsewhere in the past five years were reported to be mainly among the poor, elderly, and labourers such as rural daily wage earners, agricultural workers, labourers and rickshaw pullers, who have no option but to work outdoors in extreme weather (BBC News, 2002; Lal, 2002). Serious health risks associated with

extreme summer temperatures and heat waves have been reported in Siberian cities too (Zolotov *et al*., 2004). Number of heat stroke patients is increasing in big cities in Japan in July and August. Duration of hours higher than 30℃ or daily maximum air temperature higher than 32℃ is the significant indecies.

The number of flood disasters and their mortality impacts are heavily skewed toward Asia, where there are high population concentrations in floodplains of major rivers, such as the Ganges-Brahmaputra, Mekong and Changjiang basins, and in cyclone-prone coastal regions such as around the Bay of Bengal and the South China Sea. Heavy rainfall has been associated with an increase in outbreaks of enteric pathogens, usually as a result of a contamination of the water supplies. In tropical Asia, endemic morbidity and mortality due to diarrhoeal disease is associated with effect of high temperatures on bacterial proliferation (Checkley *et al*., 2000). Baseline prevalence of diarrhoeal disease is also linked to poverty and hygiene behaviour, rather than poor water quality. In India and Bangladesh, diarrhoeal diseases and outbreaks of other infectious diseases (e.g. cholera, hepatitis, vector-borne disease) have been reported to increase significantly after severe floods (Durkin *et al*., 1993). El Niño-related droughts are reported to have been associated with malaria outbreaks in Sri Lanka (Bouma *et al*., 1996), suburb of Manila (Glantz, 2001) and Irian Jaya (Bangs *et al*., 1999). Epidemics can follow drought in very humid regions, when river flow decreases sufficiently to allow mosquito breeding. In many desert fringe regions such as in Rajasthan bordering the Thar Desert, linkages between annual rainfall and malaria have been observed (Akhtar *et al*., 1996).

Future rises in coastal water temperatures due to climate change may have direct influence on the abundance and/or toxicity of Vibrio cholera. The bimodal seasonal pattern of cholera in Bangladesh is reported to have followed sea surface temperatures in the Bay of Bengal and seasonal plankton abundance (a suggested environmental reservoir of the cholera pathogen, Vibrio cholera) (Colwell, 1996; Lobitz *et al*., 2000; Bouma *et al*., 2001; Pascual *et al*., 2002). Interannual variability of cholera incidence in Dhaka, Bangladesh, between 1980 and 1998 was associated with ENSO (Pascual *et al*., 2000). An analysis of historical data for Bengal (1890-1940) indicates that El Niño related cholera outbreaks were confined to the coastal regions. The relationship between cholera and ENSO in Dhaka appears to have changed over time, becoming stronger in the last two decades (Rodo *et al*., 2002). Outbreaks of dengue or H-fever, diarrhoea and cholera in various parts of the Philippines associated with ENSO of 1997/98 have also been reported. Poverty, lack of access to safe drinking water and poor sewerage system has exacerbated the spread of these communicable diseases in recent years (Glantz, 2001).

10.2.5 Other stressors

Accurate understanding and description of the current and future impacts of climate change and variability on key ecosystems and resources hinge on a fair knowledge about how the impacts of climate change interact with changes in population, development, and land use and land cover changes. Climate change can be quite potent in altering terrestrial ecosystems. The impacts of climate change can however be amplified or muted by population growth, development and land use and land cover change. Climate change is likely to increase country-scale inequity, within the present generation and between present and future generations, particularly in developing countries. Given this potential vulnerability, steps to lessen non-climatic stressors while strengthening adaptive and mitigative capacity could well enhance sustainable development.

10.2.5.1 Population growth

The Asia population has grown 2.57 times, from 1.44 billion to 3.69 billion, during 1950-2000. Population growth particularly in countries with already high population density is inextricably

associated with the increasing pressure on the natural resources and the environment as the demands for goods and services expand. Utilization of natural resources almost inevitably entails alteration of the environment and ecosystems even when carried out in the most prudent manner. While changes in the environment and ecosystems can at times be beneficial the bottom line more often reflects net degradation than development. Some of the key impacts of increasing population include those linked with the intensification of use of natural forests including mangroves, agriculture, industrialization and urbanization.

In the developing world, the remaining natural flood plains are disappearing at an accelerating rate, primarily as a result of changes in land use and hydrological cycle particularly changes in streamflows due to climatic and human related factors. The future increase of human population will lead to further degradation of riparian areas, intensification of the land and water use, increase in the discharge of pollutants, and further proliferation of species invasions. The most threatened flood plains will be those in South and Southeast Asia.

In Southeast Asia, population growth particularly in the uplands continues to exert pressure on the remaining forests in the region. Encroachment into forest zones for cultivation, grazing, fuel wood and other purposes has been a major cause of the loss and alteration of natural forests. Shifting cultivation being practiced by more than 20 million people inhabiting the uplands of the Philippines is the main source of forest degradation problem there (Pulhin, 2005). Under favourable circumstances however, upland farming systems can be sustainable land use options.

In Asia, the pressure on land in the 21st century will increase due to the increasing food grain demand for the growing population, the booming economic development, as well as climate change. This will be exacerbated by the increasing scarcity of arable lands as a result of using vast agricultural lands to support industrialization and urbanization in pursuit of economic development (Zeqiang *et al*., 2001).

10.2.5.2 Development activities

Development to a large extent is responsible for much of the greenhouse gases emitted into the atmosphere that drives climate change. On the other hand development greatly contributes in reducing vulnerability to climate change and in enhancing the adaptive capacity of vulnerable sectors.

The rapid expansion of irrigation agriculture early in the 1960s led to a significantly large increase in water withdrawals from the Amu Darya and Syr Darya rivers in Central Asia. As a result, the Aral Sea has been shrinking at an alarming rate over the past four decades. The process taking place in the Aral Sea region could be referred to as anthropogenic desertification. The river deltas and other natural habitats in Aral Sea have been adversely affected. Serious health hazards have also occurred by extensive use of chemical fertilizers and pesticides that have contaminated both the soil and the water in the region.

Rates of both total forest loss and forest degradation are highest in Asia than anywhere else in the world. The conversion of forested area to agriculture in Asia during the past two decades occurred at a rate of 30,900 km^2 per year. In many developing countries of Asia, small scale fuel wood collection and industrial logging for exports of timber and conversion of forests into estate crop plantation (i.e. oil palm) and mining are also responsible for deforestation. For some countries in the Middle East, notably Kuwait, and in China forest cover has increased greatly during the past decade – this is due to relatively little original tree cover in these arid countries, but also an increase due to policies of tree planting and availability of irrigation.

10.3 Future projections of climate and socioeconomic indicators

10.3.1 Future climate change scenarios

Climate change scenarios that are based on an ensemble of results as inferred from five A-O GCM experiments, namely those of CCSR-NIES (Japan), CSIRO (Australia), ECHAM4 (Germany), HADCM3 (UK) and NCAR-PCM (USA) for the six sub-regions of Asia on annual and seasonal mean basis are presented in Table 10.5 below. The projections on likely increase in area – averaged surface air temperature and percent change in area – averaged precipitation (with respect to the baseline period 1961-1990) presented here are based on two extremes of the GHG emission scenarios corresponding to the highest (A1FI) and lowest (B1) emission pathways as envisaged in Special Report on Emission Scenarios (SRES) and for the four seasons and three 30 year time slices averaged over 2020s, 2050s and 2080s. Since not all of the said A-O GCM experiments have been conducted for all the six SRES scenarios, pattern scaling approach is followed for inferring these regional projections (Ruosteenoja *et al*., 2003).

In general, projected warming over all sub-regions of Asia is higher during northern hemispheric winter than during summer for all time periods. Most pronounced warming is projected at high latitudes in North Asia. Relatively higher increases in minimum temperature than in maximum temperature are projected over most of Asia on an annual mean basis, as well as during the winter—hence a decrease in diurnal temperature range (DTR). Xu (2003) and Gao *et al*. (2003) suggested that the annual mean surface air temperature change over Tibet Plateau would be greater than the surrounding regions by the end of this century. The warming would be significant in high altitudes along Himalayas where the temperature increase can reach 3.4ºC. Recent modelling experiments with high resolution global climate models suggest substantial increase in annual mean temperature over Arctic regions, arid regions and highlands of Asia while the rise in temperature is lowest over western China and eastern Siberia (Uchiyama *et al*., 2005).

The precipitation is projected to increase over most of the Tibetan Plateau with the highest increase of about 40% in Southwestern and Northeastern part. An overall increase of only about 10 to 15% in summer monsoon precipitation is reported for the future over South Asia (Lal *et al*., 2001; Rupa Kumar *et al*. 2001). The projected increase in area-averaged monsoon rainfall over the Indian subcontinent is within the currently observed range of interannual variability which is sufficiently large to cause devastating floods or serious drought. During winter, South Asia may experience between 5 and 25% decline in rainfall (Lal *et al*., 2001; Kripalani *et al*., 2003). The decline in wintertime rainfall is significant and may lead to droughts during the dry summer months. Hulme *et al*. (1999a, b) suggest that rainfall will increase across Northern Indonesia and the Philippines, and decrease over the southern Indonesian archipelago in the future. Downscaled GCM results suggest that total annual rainfall in Philippines would increase in future (Cruz *et al*., 2005).

The average daily rainfall would decrease during the drier months (i.e., December to April) and increase during the wetter months (i.e., May to November). The inter-model differences are, however, significantly large for the projections of precipitation change, suggesting rather low confidence in the future projections of regional precipitation.

Table 10.5: *Projected changes in surface air temperature and precipitation for sub-regions of Asia under SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) pathways for three time slices, namely 2020s, 2050s and 2080s.*

Sub-regions	Season*	2010-2039				2040-2069				2070-2099			
		Temperature, °C		Precipitation, %		Temperature, °C		Precipitation, %		Temperature, °C		Precipitation, %	
		A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1	A1FI	B1
North Asia	DJF	2.94	2.69	16	14	6.65	4.25	35	22	10.45	5.99	59	29
	MAM	1.69	2.02	10	10	4.96	3.54	25	19	8.32	4.69	43	25
	JJA	1.69	1.88	4	6	4.20	3.13	9	8	6.94	4.00	15	10
	SON	2.24	2.15	7	7	5.30	3.68	14	11	8.29	4.98	25	15
Central Asia	DJF	1.82	1.52	5	1	3.93	2.60	8	4	6.22	3.44	10	6
	MAM	1.53	1.52	3	-2	3.71	2.58	0	-2	6.24	3.42	-11	-10
	JJA	1.86	1.89	1	-5	4.42	3.12	-7	-4	7.50	4.10	-13	-7
	SON	1.72	1.54	4	0	3.96	2.74	3	0	6.44	3.72	1	0
Tibetan Plateau	DJF	2.05	1.60	14	10	4.44	2.97	21	14	7.62	4.09	31	18
	MAM	2.00	1.71	7	6	4.42	2.92	15	10	7.35	3.95	19	14
	JJA	1.74	1.72	4	4	3.74	2.92	6	8	7.20	3.94	9	7
	SON	1.58	1.49	6	6	3.93	2.74	7	5	6.77	3.73	12	7
East Asia	DJF	1.82	1.50	6	5	4.18	2.81	13	10	6.95	3.88	21	15
	MAM	1.61	1.50	2	2	3.81	2.67	9	7	6.41	3.69	15	10
	JJA	1.35	1.31	2	3	3.18	2.43	8	5	5.48	3.00	14	8
	SON	1.31	1.24	0	1	3.16	2.24	4	2	5.51	3.04	11	4
South Asia	DJF	1.17	1.11	-3	4	3.16	1.97	0	0	5.44	2.93	-16	-6
	MAM	1.18	1.07	7	8	2.97	1.81	26	24	5.22	2.71	31	20
	JJA	0.54	0.55	5	7	1.71	0.88	13	11	3.14	1.56	26	15
	SON	0.78	0.83	1	3	2.41	1.49	8	6	4.19	2.17	26	10
Southeast Asia	DJF	0.86	0.72	-1	1	2.25	1.32	2	4	3.92	2.02	6	4
	MAM	0.92	0.80	0	0	2.32	1.34	3	3	3.83	2.04	12	5
	JJA	0.83	0.74	-1	0	2.13	1.30	0	1	3.61	1.87	7	1
	SON	0.85	0.75	-2	0	2.22	1.32	-1	1	3.72	1.90	7	2

10.3.2 Likely changes in extreme climatic events

Pronounced year to year variability in climate over East, South and Southeast Asia has been linked to ENSO. As global temperatures increase, the Pacific climate will tend to resemble a more El Niño-like state (Timmermann *et al*., 1999). An increased frequency of ENSO events and a shift in their seasonal cycle in a warmer atmosphere is suggested (Collins, 1999). The enhanced anomalous warming of the eastern equatorial Pacific Ocean has implications for increasing the likelihood of droughts and floods during summer in many of the East, South and Southeast Asian countries (Li *et al*., 2003). Future seasonal precipitation extremes in South and Southeast Asia associated with ENSO events are likely to be more intense (Ashrit *et al*., 2003).

An increase in tropical cyclone intensities is suggested in a warmer atmosphere (Walsh, 2004), though there is no conclusive evidence to suggest that cyclone frequencies or their preferred locations may change in the future. A possible increase in cyclone intensity of 10-20% for a rise in sea surface temperature of 2 to 4°C relative to the current threshold temperature is very likely (Knutson *et al*., 2004). Amplification in storm surge heights should result from the occurrence of stronger winds with increase in sea surface temperatures and low pressures associated with tropical storms resulting in an enhanced risk of coastal disasters along the coastal regions of East, South and Southeast Asian Countries.

High resolution global climate models suggest a decline in the number of frost days over the Arctic, Tibet, eastern China, Korea and Japan (Uchiyama *et al*., 2005). An increase in extreme temperature range (ETR) is likely over Middle East countries, central India, western China through Central Asia and Indochina Peninsula while a decrease in ETR is suggested over Russia, the eastern half of China, Korea and Japan. Significant increases in growing season length are projected over eastern Tibet, China's Changjiang River basin, Korea and Japan. A pronounced increase in heat wave duration index is likely over the arid regions and the highlands of Asia.

Several attempts have been made to generate more confident regional climate change scenarios using the data from an ensemble of regional climate modelling experiments covering East, South and Southeast Asia. These regional projections suggest that the annual mean area-averaged temperature over East Asia may increase by about 5ºC and precipitation would enhance by 6% (slightly warmer and wetter than the GCM based projections) by the end of this century (Kwon *et al*., 2004; Boo *et al*., 2005). Rise in temperature ranging from 2.2ºC over South China to 2.8ºC over North China is also projected. The precipitation would increase over central-west China by over 20% (Gao *et al*., 2001; 2002). Areas of precipitation decline are likely over Northeast and North China (up to –10%). The diurnal temperature range over most of Asia is likely to decrease due to the higher increase of minimum temperature. The number of hot spell days in summer will significantly increase while the number of cold spell days in winter will significantly decrease through out Asia.

A series of numerical experiments conducted with a high resolution regional climate model to assess future extreme climate events such as heat wave, heavy rainfall and typhoon over East Asia, including Japan and Korea (Emori *et al*., 2000; Kato *et al*., 2000; Sato, 2000; Ichikawa, 2004; Kurihara *et al*., 2005; Japan Meteorological Agency, 2005) suggest that heat wave conditions over Japan are likely to enhance in the future (Fig. 10.2). Extreme daily precipitation, including that associated with typhoon, would be further enhanced over Japan due to the enhancement of atmospheric moisture availability (Hasumi *et al*., 2004). The increases in summer mean precipitation over south Japan are also projected to be significantly large for the future (Fig. 10.3).

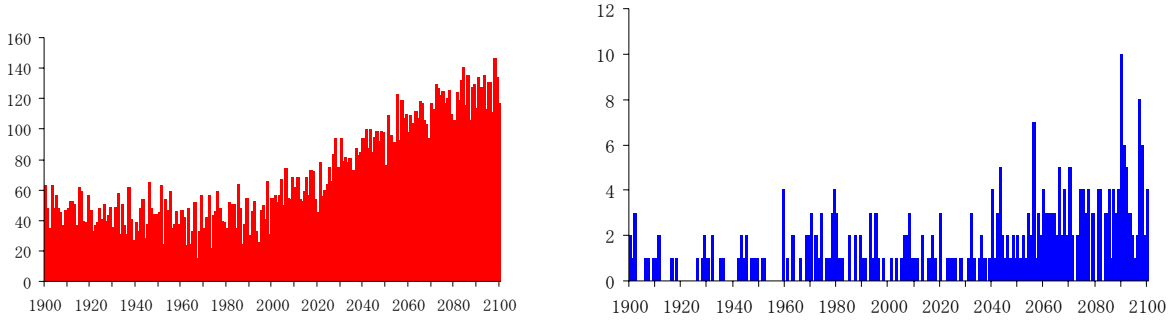

Fig. 10.2: *Projected number of hot days (>30°C) and heavy rainfall (>100mm/day) by the high resolution GCM (Hasumi et al., 2004)*

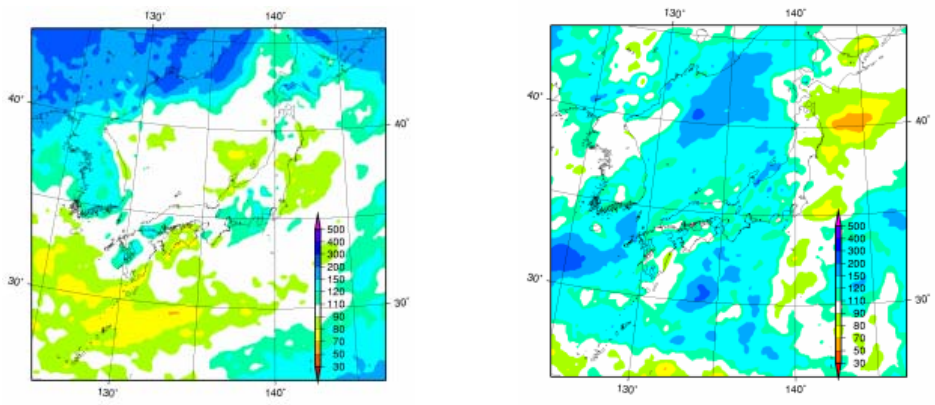

Fig. 10.3: *Projected change in monthly mean rainfall during 2080-2100 period compared to 1981-2000 period simulated by a high resolution regional climate model (Left: January, right: July, Kurihara et al., 2005).*

10.3.3 Sea level rise

With over a decade of precision sea level measurements from satellite altimetry in hand and with the recent launch of new satellite missions addressing different aspects of sea level change, observationally, we have more information on sea level change than ever before. The geocentric rate of global mean sea level rise over the last decade (1993–2003) is now known to be +2.8 ± 0.4 mm/yr, as determined from TOPEX/ Poseidon and Jason altimeter measurements and 3.1 mm/yr if the effects of postglacial rebound are removed (Chambers, 2003; Cazenave *et al*., 2004). This rate is significantly larger than the historical rate of sea level change measured by tide gauges during the past decades (in the range of 1–2 mm/yr) and an order of magnitude larger than the average rate over the previous several millennia (Douglas, 2001; Church *et al*., 2001; Cabanes *et al*., 2004; Munk, 2002 & 2003). In coastal areas of Asia, the current rate of sea level rise is reported to be between 1 to 3 mm per year – marginally greater than the global average (Dyurgerov *et al*., 2000; Nerem *et al*., 2001; Antonov *et al*., 2002; Woodworth *et al*., 2004). A rate of sea level rise of 3.1 mm per year has been reported over the past decade compared to 1.7-2.4 mm per year over the 20th century as a whole (Arendt *et al*., 2002; Rignot *et al*., 2003), which suggests that the rate of sea level rise has accelerated relative to the long term average.

For a quadrupling of greenhouse gas concentrations, global mean sea level rise from thermal expansion of oceans is projected to be between 1 to 4 meters (Church *et al*., 2001). Warming over Greenland of 5.5ºC, which is consistent with mid-range greenhouse gas stabilization scenarios, would melt the Greenland ice sheet and could contribute to a sea level rise of about 3 meters in 1,000 years (De Angelis *et al*., 2003; Sabadini *et al*., 2002; Rignot *et al*., 2004). A rapid collapse of the West Antarctic Ice Sheet leading to a sea level rise of several meters is very unlikely during the 21st Century (Rignot *et al*., 2002; Rignot *et al*., 2004). The rate and magnitude of sea-level change in the next century is likely to vary from region to region around the globe. However to date, there is little agreement as to the pattern of sea level rise.

10.3.4 Socioeconomic scenarios

The publication of the IPCC Special Report on Emissions Scenarios in 2000 presented a useful starting point for impact assessors to construct a range of mutually consistent regional climate and non-climatic scenarios. In the SRES framework four narrative storylines (A1, A2, B1, B2) were

developed which provide broadly qualitative and quantitative descriptions of regional changes on socio-economic development (e.g. population, economic activity), energy services and resource availability (e.g. energy intensities, energy demand, structure of energy use), land use and land cover, greenhouse gases and sulphur emissions, atmospheric composition (e.g. CO_2 concentration, tropospheric ozone etc.). The Asia region includes all developing (non-Annex I) countries in Asia (excluding the Middle East). GHG emissions were quantified reflecting socio-economic development such as energy use, land use changes, industrial production process, and so on. The Population and GDP projections for Asia are illustrated in Fig. 10.4. The population growth shows a wide range among four scenarios; the differences between highest (SRES-A2) and lowest (SRES-A1 and B1) population scenarios are 1.54 billion people in 2050 and 4.5 billion people in 2100. For GDP growth, the highest economic growth is assumed in SRES-A1 scenario while the lowest economic growth is in SRES-A2 scenario. The GDPs in SRES-A1 scenario in 2050 and 2100 approach 4.2-fold and 3.6-fold of GDPs in SRES-A2 scenario respectively.

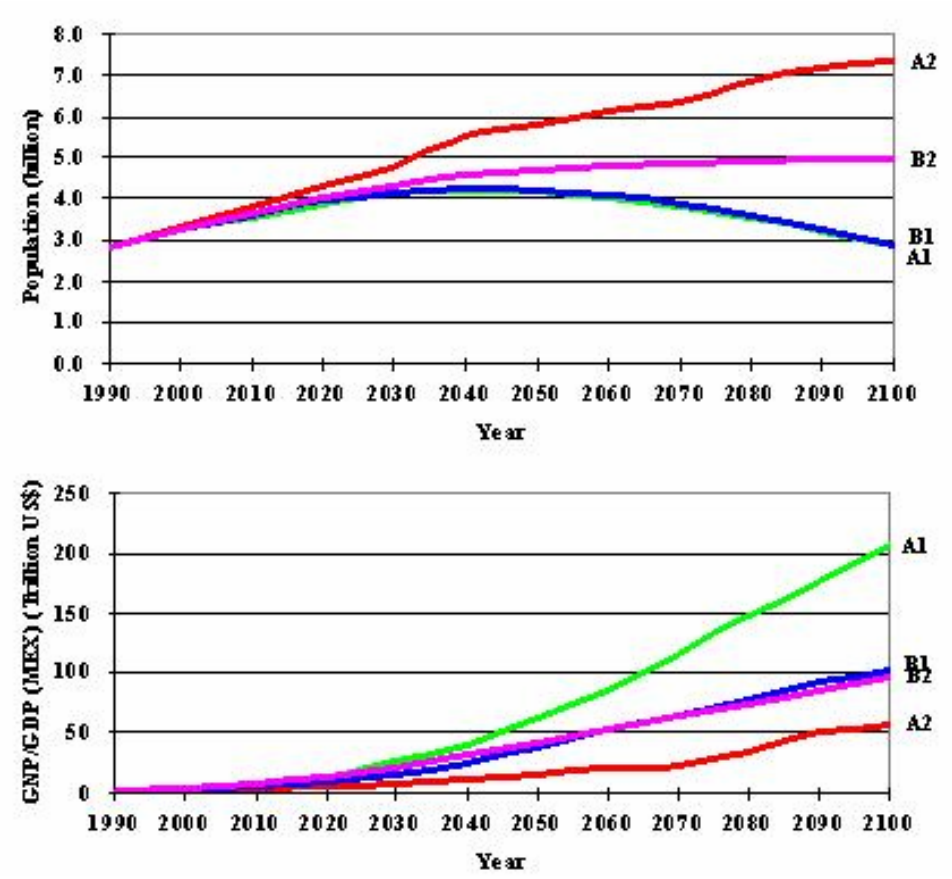

Fig. 10.4: *Population and GDP projections at ASLA region (IPCC-SRES Marker Scenarios)*

Following the SRES, several global scenarios (Post-SRES, GEO-3, etc) have been developed (Morita *et al*., 2001; UNEP, 2002). Furthermore, long-term GHG stabilization scenarios according to alternative development paths for major world regions, based on the non-intervention emission scenarios has been developed and GHG emissions from energy use, land use changes, and industrial production processes have been simulated over a wide range of mitigation policies adopted as responses to climate changes (Kainuma *et al*., 2003). The results demonstrate that: (a) to achieve stabilization at a different GHG concentration level, it is essential to have a policy package to reach the target concentration level, rather than a single policy; (b) energy efficiency improvement and introduction of renewable energy make a key contribution to the reduction of GHG emissions as a

result of such a policy package; and (c) the developing world has the potential to substantially reduce GHG emissions with enhanced knowledge and technology transfer from the developed countries.

10.4 Key future impacts and vulnerabilities

10.4.1 Agriculture and food security

10.4.1.1 Production and quality

Substantial decreases in cereal production potential are expected as a consequence of climate change in Asia by the end of this century. As a consequence of the combined influence of fertilization effect and the accompanying thermal stress and water scarcity (in some regions) under the projected climate change scenarios, rice production in Asia could decline by 3.8% by the end of the 21st century (Murdiyarso, 2000). Regional differences in the response of crop (wheat, maize, rice) yields to projected climate change are also significant (Parry *et al*., 1999, Rosenzweig *et al*., 2001). The projected warming accompanied by a 30% increase in tropospheric ozone and 20% decline in humidity is expected to decrease the grain and fodder productions by 26% and 9% respectively in North Asia (Izrael, 2002). Crop yields could increase up 20% in East and Southeast Asia while it could decrease up to 30% in Central and South Asia even though the direct positive physiological effects of CO_2 are taken into account. For the warming projections under A1FI emission scenarios (*see Table 10.5*), substantial decreases in crop yields have been suggested in parts of Asia with expected losses up to as high as 30% (Parry *et al*., 2004). A 5 to 12% decline in net country wide grain production in Russia as a whole has been estimated by the 2070s.

The statistics on wheat productivity in past few decades suggests that its production potential is on the decline in large portions of South Asia and the southern part of East Asia (Fischer *et al*., 2002). The crop simulation modelling studies based on future climate change scenarios have indicated that substantial loses are likely in rainfed wheat in South and Southeast Asia (Fischer *et al*., 2002). For example, 0.5°C rise in winter temperature would reduce wheat yield by 0.45 tons per hectare in India (Lal *et al*., 1998; Kalra *et al*., 2003). Studies also suggest that a 2°C increase in mean air temperature could decrease rainfed rice yield by 5-12% in China (Lin *et al*., 2004). In South Asia, the drop in yields in non-irrigated wheat and rice will be significant for a temperature increase of beyond 2.5°C incurring a loss in farm level net revenue of between 9% and 25% (Lal *et al*., 1998). The net cereal production in South Asian countries is projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change projections (Lal, 2005). The changes in cereal crop production potential indicate an increasing stress on resources induced by climate change in many developing countries of Asia.

10.4.1.2 Farming system and cropping areas

Climate change can affect not only crop production per unit area but also the area of production. Most of the arable land that is suitable for cultivation in Asia is already in use (IPCC, 2001). A decline in potentially good agricultural land in East Asia (including Japan) and substantial increases in suitable areas and production potentials in currently cultivated land in Central Asia are reported (Fischer *et al*., 2002). A northward shift of agricultural zones is likely such that the dry steppe zone in eastern part of Mongolia would push the forest-steppe to the north resulting in shrinking of the high mountainous and forest-steppe zones and expansion of the steppe and desert steppe (ref.?). Studies suggest that, by the middle of this century in northern China, tri-planting boundary will shift by 500 km from Changjiang River valley to Yellow River basin, and double planting regions will move towards the existing single planting areas, while single planting areas will shrink by 23% (Wang,

2002). Suitable land and production potentials for cereals may marginally increase in the Russian Federation and in East Asia (Fischer *et al*., 2002).

More than 28 million hectare area in South and East Asia requires strong expansion of irrigation for sustained productivity (FAO, 2003). For example, agricultural irrigation demand in arid and semi-arid regions of East Asia is estimated to increase by 10% for increase in temperature of 1^{o}C (Liu, 2002). The rainfed crops in the plains of north and northeast China would face water-related challenges in coming decades due to increases in water demands and soil-moisture deficit associated with projected decline in precipitation (Tao *et al*., 2003b).

Since land is a fixed resource for agriculture, the need for more food in South Asia could only be met through higher yields per units of land, water, energy and time such as through precision farming. Enhanced variability in hydrological characteristics will continue to affect strategic grain supplies and food security of many nations in Asia. Intensification of agriculture will be the most likely means to meet the food requirements of the billions in Asia.

10.4.1.3 Livestock, fishery, aquaculture

Consumption of animal products such as meat and poultry has increased steadily in comparison to milk and milk products linked protein diets in the past few decades (FAO, 2003). However, in most regions of Asia (India, China, and Mongolia) pasture availability limits the expansion of livestock numbers. Cool temperate grassland is projected to shift northward with climate change and the net primary productivity will decline (Therendash *et al*., 2005; Sukumar *et al*., 2003, Christensen *et al*., 2004). The limited herbaceous production, heat stress from higher temperature, limited water intake due to decrease in rainfall could cause reduced milk yields in animals and increased incidence of some diseases.

The Asia-Pacific region is the world's largest producer of fish, from both aquaculture and capture fishery sectors. In 2002, this amounted to 46.9 million tonnes from aquaculture (91% of global aquaculture production) and 44.7 million tonnes from capture fisheries (FAO, 2004a, b). Most of the growth in both aquaculture and capture fisheries has come from China and other South and Southeast Asian countries. Japan and Korea have shown a steady reduction in the supply of capture fish and consistent production in aquaculture in recent years. The fishery resources of Asia are being depleted by overfishing, excessive use of pesticide and industrial pollution. The increase in marine culture products and decline in the marine fishery output is the current trends in commercial fishery activity. Recent studies suggest a reduction of primary production in the tropical oceans because of changes in oceanic circulation in a warmer atmosphere. The tunas catch of East Asia and Southeast Asia is nearly one-forth of the world’s total. A modeling study showed significant large-scale changes of skipjack tuna habitat in the equatorial Pacific under projected warming scenario (Loukos *et al*., 2003). Marine fishery in China is facing threats from overfishing, pollution, red tide, and other climatic and environmental pressures. Principal marine fishery species, like ribbon fish, small and large yellow croakers, have obvious zoned distribution and seasonal feeding migration or spawning migration. The migration route and migration pattern, and hence regional catch, may be greatly affected by global climate change (Su *et al*., 2002; Zhang *et al*., 2004). Increased frequency of El Niño events likely in a warmer atmosphere could also lead to measurable declines in fish larvae abundance in coastal waters of South and Southeast Asia. These phenomena are expected to contribute to a general decline in fishery production in the coastal waters of East, South and Southeast Asia. Arctic marine fishery would also be greatly influenced by climate change. Moderate warming is likely to improve the conditions for some economically gainful fisheries, such as cod and herring. Higher temperatures and reduced ice cover can increase productivity of their prey and

provide more extensive habitats. In contrast, the northern shrimp will decrease with rise in sea surface temperatures (ACIA, 2004).

The impact of climate change on Asian fishery depends on the complicated food chain in the surrounding oceans, which are likely to be disturbed by the climate change. Future changes in ocean currents, sea level, sea water temperature, salinity, wind speed and direction, strength of upwelling, the mixing layer thickness and predators to climate change have the potential to substantially alter fish breeding habitats and food supply for fish and ultimately the abundance of fish populations in Asian waters (IPCC, 2001).

Nonetheless, aquaculture production is expected to continue its upward trend in the foreseeable future. However, climate change may have dramatic impacts on fish production, reducing the supply of fish meal and fish oils. The market structure for fish meal is a key factor in determining whether increasing aquaculture production can affect fish meal prices (Asche *et al*., 2004). Increasing sea surface temperature has the potential to increase the intensity and frequency of disease outbreaks, exerting negative effects on marine aquaculture.

The population in land locked countries and inland regions of Asia consume mostly freshwater fish. Fisheries at higher elevations are likely to be affected by lower availability of oxygen due to rise in surface air temperatures. In the plains, the timing and amount of precipitation may also affect the migration of fish species from the river to the floodplains for spawning, dispersal, and growth (FAO, 2003). Sea level rise may also cause saline water fronts to penetrate further inland, which could increase the habitat of brackish water fisheries and coastal inundation could significantly damage the aquaculture industry.

10.4.1.4 Future food supply and demand

Half the world's population is located in Asia. There are serious concerns about the prevalence of malnutrition among poorer and marginal groups, particularly rural children, and about the large number of people below the poverty line in many countries. Large uncertainties in our understanding as to how the regional climate change will impact the food supply and demand in Asia continue to prevail in spite of recent scientific advances. Because of increasing interdependency of global food system, the impact of climate change on future food supply and demand in Asia as a whole as well as in countries located in the region depends on what happens in other countries (Fischer *et al*., 2002). For example, India's surplus grain in past few years has been used to provide food aid to drought-affected Cambodia. However, increasing urbanization and population in Asia certainly will result in increased food demand and reduced supply due to limited availability of cropland area and yield declines projected in most cases (Murdiyarso, 2000; Wang, 2002; Lin *et al*., 2004).

Food supply or ability to purchase food directly depends on income and price of the products. The global cereal prices have been projected to increase more than three-fold by the 2080s as a consequence of decline in net productivity due to projected climate change (Parry *et al*., 2004). Localized increases in food prices could be frequently observed. Subsistence producers growing crops, such as sorghum, millets, etc, could be at the greatest risk, both from a potential drop in productivity as well as from the danger of losing crop genetic diversity that has been preserved over generations. The risk of hunger, thus, remains very high in several developing countries of Asia since a large portion of population in majority of these countries has low purchasing power.

Grasslands, livestock, and water resources are likely to be most vulnerable to climate change in Central Asia because they are located mostly in marginal areas. Food insecurity and loss of livelihood is further exacerbated by the loss of cultivated land and nursery areas for fisheries by

inundation and coastal erosion in low-lying areas of the tropical Asia. Management options, such as better stock management and more integrated agro-ecosystems could improve land conditions and counteract pressures arising from climate change.

10.4.1.5 Extreme climatic events and pests

Many recent studies (Rosenzweig *et al*., 2001; Natsagdorj *et al.*, 2005; Kripalani *et al*, 2003; Zhang *et al*., 2004) have emphasized high confidence in the projected increase in the frequency and intensity of extreme weather events such as droughts, floods, and tropical cyclones etc., particularly those associated with ENSO. Alterations in the patterns of extreme events, such as the increased frequency and intensity of droughts, will have much more serious consequences for chronic and transitory food insecurity than shifts in the patterns of average temperature and precipitation. These rainfall deficits can dramatically reduce crop yields and livestock numbers in rainfed production systems that are common in the semi-arid Asia. Humid areas in Asia are also vulnerable to changes in the length of the growing season and from extreme events, such as tropical cyclones.

Some studies (Rosenzweig *et al*., 2001; FAO, 2004c) concur that higher temperatures and longer growing season would result in increase in pest population in temperate regions of Asia. Warmer winter temperatures would reduce winter kill favouring the increase of insect population. Overall temperature increases may influence crop pathogen interactions by speeding up pathogen growth rates, which increases reproductive generations per crop cycle, by decreasing pathogen mortality due to warmer winter temperatures, and by effects on the crop itself that leave the crop more vulnerable.

Climate change, as well as changing pest and disease patterns, will affect how food production systems operate in the future. This will have a direct influence on food security and poverty levels, particularly in countries with a high dependency on agriculture. In many cases, the impact will be felt directly by the rural poor, as they are often closely linked to direct food systems outcomes for their survival and are less able to substitute losses through food purchases. The urban poor can also be affected negatively because declining food production due to any of these factors will change food prices.

10.4.2 Hydrology and water resources

10.4.2.1 Water availability and demand

The most serious threat caused by climate change in Asia is water scarcity characterized by temperature increase and precipitation decrease mainly in central Asia. Climate change is likely to cause a major change in the variability of river runoff in some parts of Russia (Peterson *et al*., 2002) such that extremely low runoff events may occur much more frequently in the crop growing regions of the Southwest. Changes in seasonality and amount of water flows from river systems are likely to occur due to climate change. Some countries in Asia produce large amounts of hydropower; Tajikistan, for example, is the third-highest producer in the world (World Bank, 2002). Changes in runoff to the catchments of river basins could have a significant effect on the power output of these countries. The large river systems in the region, the Euphrates and Tigris, have a number of dams that are used for irrigation and water supply as well as for hydropower. If there is a reduction in total runoff due to climate change, the increased demand for agricultural and hydropower activities could place more pressure on water resources.

Water resources for irrigation from available surface and ground water sources in North China will meet only 70% of water requirement for agricultural production (Liu *et al*., 2001; Qin *et al*., 2002).

In parts of central Asia, regional increases in temperature will lead to an increased probability of events such as mudflows and avalanches that could adversely affect human settlements (Iafiazova, 1997). As mountain glaciers continue to disappear, the volume of summer runoff eventually will be reduced as a result of loss of ice resources. Consequences for downstream agriculture, which relies on this water for irrigation, will be unfavorable in most countries of South Asia. The thawing volume and speed of snow cover in spring is projected to accelerate in Northwest China and western part of Mongolia and the thawing time could advance, which will increase some water source, and may lead to flood in spring but significant shortages in wintertime water availability for livestock are projected by the end of this century (Batima *et al*., 2004b, 2005b)

10.4.2.2 Water quality

Overexploitation of groundwater in many countries of Asia has resulted in a drop in its level leading to ingress of seawater in coastal areas making the subsurface water saline. India, China and Bangladesh are especially susceptible to increasing salinity of their groundwater as well as surface water resources especially along the coast due to increase in sea level as a direct impact of global warming (Han *et al*., 1999). Rising sea level by 0.4-1.0 m can induce saltwater intrusion 1-3 km more inland in the Zhujiang Estuary (Huang *et al*., 2000). Increasing frequency and intensity of droughts in the catchment area will lead to more serious and frequent saltwater intrusion in the estuary (Xu, 2003; Thanh *et al*., 2004; Huang *et al*., 2005) and thus deteriorate surface and ground water quality.

10.4.2.3 Implications of droughts and floods

The global warming would cause an abrupt rise of water quantity as a result of snow or glacier melting that in turn, would lead to floods. The floods quite often are caused by rise of river water level due to blockage of channel by drifting ice, as it happened in Central Siberia, Lensk, or enormous precipitation from destructive shower cyclone, as it was in North Asia Pacific const, Vladivostok (TNCR, 2002). Projected increase in surface air temperature in Northwest China will result in a 27% decline in glacier area (equivalent to the ice volume of 16184 km^3), in a 10 to 15% decline in frozen soil area, increase in flood and debris flow and more severe water shortage (Qin, 2002). The duration of seasonal snow cover in alpine areas namely Tibet Plateau, Xinjiang and Inner Mongolia will shorten and snow cover will thaw out in advance of spring season leading to a decline in volume and resulting in severe spring droughts. Between 20 and 40% reduction of runoff per capita in Ningxia, Xinjiang and Qinghai Province is likely by the end of 21st century (Tao *et al*., 2005). However, the pressure due to increasing population and social economic development on water resources is likely to be larger. Higashi *et al.* (2006) project future flood risk using 2-day precipitation of the 12 GCMs. The model ensemble average 200-year quantiles in Tokyo, Japan during 2050 – 2300 under SRES A1B is 1.07-1.20 times larger than the present condition, resulting in flood risk in terms of high water discharge in Tama River basin rise by 10 – 26%.

The per capita availability of freshwater including groundwater available in India is expected to drop from current availability of about 1905 m^3 to 1480 m^3 in the next decade due to increase in population coupled with no further augmentation of water resources and also its consequent decrease over the same time due to consumption. India will reach a state of water stress before 2025 when the availability falls below 1000 m^3 per capita (CWC, 2001). The projected decrease in the winter precipitation over Indian subcontinent would reduce the total seasonal precipitation during December, January and February implying lesser storage and greater water stress during the lean monsoon period. Intense rain occurring over fewer days, which implies increased frequency of floods during the monsoon, will also result in loss of the rain water as direct runoff resulting in reduced groundwater recharging potential.

Expansion of areas under severe water stress will be one of the most pressing environmental problems in South and Southeast Asia in the foreseeable future as the number of people living under severe water stress is likely to increase substantially in absolute terms. For example, annual flow of Red river is projected to reduce by 13 to 19% and that of Mekong River by 16 to 24% by the end of 21st century (ADB, 1994). Major structural and technological changes (effective water-related policies, modification in lifestyle and technological transfer) should lead to decreases in water withdrawals and hence water stress. More sustainable water use based on improvements in water use efficiency and marked changes in irrigation sector would be needed.

10.4.3 Coastal and low lying areas

10.4.3.1 Coastal erosion and inundation of coastal lowland

Average global sea-level rise over the second half of the 20th century has been 1.8 ± 0.3 mm per year, and sea-level rise of the order of 2-3 mm per year is considered likely during the early 21st century as a consequence of the greenhouse effect (White *et al*., 2005; Woodrofee *et al*., 2005). However, the sea level rise in Asia is geographically variable, and additional half a meter of sea level rise is projected for Arctic during this century (ACIA, 2004). The rising rates of sea level vary considerably from 1.5 to 4.4 mm per annum along the East Asia coast due to regional variation in land surface movement (Mimura *et al*., 2004). The projected rise of mean high water level can be one-time greater than that of mean sea level (Chen, 1991; Zhang *et al*., 2000). The projected relative sea level rise (RSLR), including that due to thermal expansion, tectonic movement, ground subsidence and the trend of rising river water level, is 40-60cm, 50-70 cm and 70-90 cm in the Zhujiang, Changjiang and Huanghe Deltas, respectively by the year 2050 (Li *et al*., 2004a, b). Choi *et al*. (2002) has reported that the regional sea level rise over the Northwestern Pacific Ocean would be much more significant compared with the global average mainly due to exceptionally large warming near the entrance of the Kuroshio extension. The slope of the land and land surface movement would also affect the relative sea level rise in the Asian Arctic (ACIA, 2004).

In Asia, erosion is the main process that will occur to land as sea level continues to rise. As a consequence, coast-protection structures built by humans will usually be destroyed by the sea while the shoreline retreats. In some coastal areas of Asia, a 30 cm rise in sea level can result in 45 m of landward erosion. Climate change and sea level rise tend to worsen the currently eroding coasts, turn the stable coasts into recession coasts, (Huang *et al*., 2000). Sea level rise will accelerate coastal erosion by different coastal processes in various climate zones. In Boreal Asia coast, the relative sea level rise may reach up to 0.5 mm per annum by the end of this century. Coastal erosion will be enhanced as rising sea level and reducing sea ice allows higher wave and storm surge to hit the shore (ACIA, 2004). The coast recession can add up to 500–600 m in 100 years, with a rate of between 4 to 6 m per annum. The coastal recession by thermal abrasion is expected to accelerate 1.4 to 1.5 times in the second half of the 21st century as compared to the current rate (Leont'yev, 2004). In monsoonal Asia, reducing sediment flux is generally a main cause of coastal erosion. There is a clear tendency of river-sediment reduction, and coastal erosion tends to be more serious in Asia (Liu *et al*., 2001).

Coastal lowland tends to be inundated by rising sea level. Sea level rise also threatens the ecologically sensitive areas such as dunes, beaches and coastal wetlands, including salt marsh habitats and mangroves. Projected sea level rise could result in the number of people being flooded each year rising by many millions (Wassmann *et al*., 2004). The potential impacts of one meter sea level rise include inundation of 5763 km^2 and 2,339 km^2 in India and in some big cities of Japan (TERI, 1996; Mimura and Yokoki, 2004). For one meter sea level rise with high tide and storm surge, the maximum inundation area is estimated to be 2,643 km^2 or about 1.2% of total area of the

Korean Peninsula (Matsen and Jakobsen, 2004). 30 cm sea-level rise would inundate coastal lowland of 81348 km^2 in China (Du and Zhang, 2000). Even under the most conservative scenario, sea level will be about 40 cm higher than today by the end of 21st century and this is estimated to increase the annual number of people flooded in coastal population from 13 million to 94 million. Almost 60% of this increase will occur in South Asia (along coasts from Pakistan, through India, Sri Lanka and Bangladesh to Burma), while about 20% will occur in Southeast Asia (from Thailand to Vietnam including Indonesia and the Philippines) (Wassmann *et al*., 2004).

The coastal lowlands below the elevation of 1000-year storm surge are widely distributed in Bangladesh, China, Japan, Vietnam, and Thailand, and hundred million people live in these areas (Nicholls, 2004). Flooding areas are related with the coastal protection level. It can be much less at highly protected coast like in economically developed Japan. In Japan, even under the present situation, an area of 861 km^2 of coastal lowland is located below high water level mainly in large cities like Tokyo, Osaka and Nagoya, where about 2 million people live and the assets cost US$ 540 billion. A one meter rise in sea level will increase people at risk up to 4.1 million (Mimura *et al*., 2004). A 30 cm rise in sea level will increase flooding areas by 5 or 6 times under non-coast-protection and existing-protection scenarios in the Changjiang and Zhujiang deltas, where the present coast protection level is high. The flooding areas in the Huanghe delta for a 100 cm rise in sea level are very close in non-protection and existing-protection scenarios, indicating that current protection level is insufficient to protect the coasts from high sea level rise (Du *et al*., 2000; Li *et al*., 2004a). Further climate warming may lead to an upward trend in tropic cyclone destructive potential, and – taking into account an increasing coastal population – a substantial increase in hurricane-related losses in the 21st century (Emanuel, 2005).

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. The projected future sea level rise could inundate low lying areas, drown coastal marshes and wetlands, erode beaches, exacerbate flooding and increase the salinity of rivers, bays and aquifers. With higher sea level, coastal regions would also be subject to increased wind and flood damage due to storm surges associated with more intense tropical storms. In addition, warming would also have far reaching implications for marine ecosystems in Asia.

10.4.3.2 Deltas, estuaries, wetland and other coastal ecosystems

Most types of world's major deltas are located in Asia. Future evolution of the major deltas in monsoonal Asia depends on changes in ocean processes and river sediment flux. Coastal erosion of the major deltas will be caused by sea level rise, intensifying extreme events (e.g. storm surge) due to climate change and excessive pumping of ground water for irrigation and reservoirs construction on the rivers. In the Tibetan Plateau and adjoining region, sediment starvation is generally the main cause of shrinking of deltas. Annual mean sediment discharge in Huanghe delta during the 1990s is only 34% of that observed during the 1950s and 1970s. The Changjiang sediment discharge will also be reduced by 50% in average after construction of the Three-Gorges Dam (Li *et al*., 2004b).

Urbanization in developing countries is proceeding exceptionally fast, although population is still largely rural in most countries, and mega cities with population more than 10 million are increasing in Asia. Many such mega cities in Asia are located on deltas formed during sea level change in the Holocene (Hara *et al*., 2005). These Asian mega cities with large population and intensified socioeconomic activities are subject to threats of climate change, sea level rise and extreme climate event. For a 1 m rise in sea level, half a million square hectares of Red river delta and from 15,000 to 20,000 km^2 of Mekong river Delta is projected to be flooded. In addition, 2,500km^2 of mangrove will be completely lost, while approximately 1,000km^2 of cultivated farm land and sea product culturing

area will become salt marshes (Tran Viet Lien *et al*., 2005).

Global warming and sea level rise will modulate environmental factors in the estuary, such as water depth, water temperature, salinity etc. Rise in water temperature and eutrophication in the Zhujiang and Changjiang Estuaries have led to formation of the bottom oxygen-deficient horizon and increase in frequency and intensity of red tides (Hu *et al*., 2001). Projected increase in frequency and intensity of extreme weather events will exert adverse impacts on aquatic ecosystems and existing habitats will be redistributed, affecting estuarine flora distribution (Short *et al*., 1999; Simas *et al*., 2001; Lu, 2003; Paerl *et al*., 2003).

The Recent risk analysis of coral reefs suggests that between 24% and 30% of the reefs in Asia are projected to be lost during next 2-10 years and 10-30 years, respectively (14% and 18% for global), unless the stresses are removed and relatively large areas are protected (Table 10.6). In other words, the loss of reefs in Asia may be as high as 88% (59% for global) in the next 30 years (Shappard, 2003; Wilkinson, 2004). If conservation measures receive increasing attention, large areas of the reefs could recover from the direct and indirect damage within the next 10 years. However, if abnormally high SST continues to cause major bleaching events and reduce the capacity of reefs to calcify due to CO2 increasing, most of human efforts will prove to be negative (Kleypas *et al*., 1999; Wilkinson, 2002).

Table 10.6: *The 2004 status of coral reefs in selected regions of Asia (Wilkinson, 2004)*

Region	Coral Reef Area (km^2)	Destroyed Reefs (%)	Reefs recovered since 1998 (%)	Reefs at Critical Stage (%)	Reefs at Threatened Stage (%)	Reefs at Low or No Threat level (%)
Red Sea	17,640	4	2	2	10	84
The Gulfs	3,800	65	2	15	15	5
South Asia	19,210	45	13	10	25	20
SE Asia	91,700	38	8	28	29	5
E & N Asia	5,400	14	3	23	12	51
Total Asia	137,750 (48.4%)	34.4	7.6	21.6	25.0	19.0

Note: Destroyed reefs: 90% of the corals lost and unlikely to recover soon; Reefs at a critical stage: 50% to 90% of corals lost or likely to be destroyed in 10 to 20 years; Reefs at threatened stage: 20 to 50% of corals lost or likely to be destroyed in 20 to 40 years.

A new study suggests that coral reefs, which have been severely affected by abnormally high SST in recent years, contain some coral species and their reef-associated microalgal symbionts that show far greater tolerance to higher SST than others. Breaching thresholds may be more realistically visualized as a broad spectrum of responses, rather than a single breaching threshold for all coral species (Hughes *et al*., 2003; Baker *et al*., 2004). This corals' adaptive response to climate change may protect devastated reefs from extinction or significantly prolong the extinction of surviving corals beyond previous assumption.

Net growth rates of coral reef, which can reach up to 8-10 mm/a, may exceed the projected rates of future sea level rise in South China Sea, so that coral reefs could not be at risks due merely to sea level rise. Water depth increased by sea level rise would lead to stormness and destruction of coral reefs (Knowlton, 2001; Wang, 2005).

10.4.4 Natural ecosystems and biodiversity

10.4.4.1 Structure, production and function of forests

Up to 50% of the Asia region's total biodiversity is at risk due to climate change. The present distribution of species in high elevation ecosystems of Himalayas is projected to shift to higher elevations as a consequence of global warming, although the rates of vegetation change are expected to be slow and colonization success would be constrained by increased erosion and overland flows in the highly dissected and steep terrains. Many species and a large population of many other species will be exterminated as a result of the synergistic effects of climate change and habitat fragmentation (Ishigami, *et al.*, 2003, 2005).

As a consequence of climate change, no significant change in spatial patterns of productivity of the forest ecosystems in Northeast China is suggested (Liu *et al*., 1998). The areal coverage of broad-leaved, Korean pine forests is projected to reduce by between 20% and 35% with a significant northward shift (Wu, 2003). About 90% of the suitable habitat for a dominant forest species beech tree (*Fagus crenata*) in Japan could disappear by the end of this century (Matsui *et al*., 2004a, b). Indonesia's forests could benefit from carbon fertilization and will have a great capacity to absorb emissions if about 20 million hectare of estate crops and forest plantations are established by the year 2030. However, the occurrence of forest dieback and of time lag before the dominant plant types adjust to altered climate and/or migrate to new sites can not be ruled out. The overall impact of climate change on the forest ecosystems of Pakistan could be negative (Siddiqui *et al*., 1999). Hajima *et al.* (2005) indicated a possibility of over-estimation on forest productivity in the former model studies because of neglect of soil nitrogen effects. They showed concretely that NPP of a model (BIOME3) without soil nitrogen effect overestimated about 20% in 2050 to about 30% in 2080 under A2 and B2 senarios in comparison with BGGC Model with soil nitrogen effect.

Annually from 12,000 to 38,000 wild fires strike the North Asia forests affecting the area from 0.5 to 3 million hectares. Fluctuations in severity of the wild fire seasons may manifest change of duration and hazard of such fires dependent on the weather conditions. With the average temperature increasing by 1°C the duration of wild fire season is growing by 30%.(Vorobyov, 2004) Higher temperatures and drought conditions would lead to growth of many pests and diseases as well. If pest population grows, a chain reaction leading to serious consequences could occur. The potential crisis with high probability of forest fire will also increase local extinction of many wild animals. Submergence of coastal areas due to sea level rise would lead to decreased habitat for breeding. With one meter rise in sea level the Sundarbans in Bangladesh will disappear and may spell the demise of the tiger and other wildlife there. The loss of habitat and wild species are at risk from changes in climate that forest fires and drought and from sea level rise.

10.4.4.2 Grasslands, rangelands and endangered species

Higher temperatures should, in general, improve the grassland productivity and prolong the pasturing time in alpine pasture, but the accompanying increase in evaporation will cause the decline of grassland productivity in areas with water scarcity. The natural grassland coverage and the grass yield in Asia, in general, are projected to decline with rise in temperature and higher evaporation (Lu *et al*., 2003). Large decreases in the natural capital of grasslands and savannahs are likely in South Asia as a consequence of climate change. Rise in surface air temperature and decline in precipitation is estimated to reduce pasture productivity in Mongolian steppe by about 10-30% except in high mountains and in Gobi where a marginal decrease in pasture productivity is projected by the end of

this century (Tserendash *et al.*, 2005). Traditional land use systems should provide conditions which would promote greater rangeland resilience due to the nomadic rangeland use, and would provide a better management strategy to cope with climate change in the region to offset the potential decrease of carbon storage and grassland productivity in the Mongolian Steppe under various climate scenarios (Ojima *et al*., 1998).

The location and areas of natural vegetation zone on the Tibetan Plateau will substantially change under the projected climate scenarios. The areas of temperate grassland and cold-temperate coniferous forest could expand while temperate desert and ice-edge desert may shrink. The vertical distribution of vegetation zone could move to higher altitude. Climate change may result in the shift of boundary of farming-pastoral transition region to the south in Northeast China, which can increase the grassland areas and provide favourable conditions for livestock production. However, as the transition area of farming-pastoral region is also the area of potential desertification, if protection measures are not taken in the new transition area, desertification may occur (Qiu *et al*., 2001; Li *et al*., 2001). More frequent and prolonged droughts as a consequence of climate change and other anthropogenic factors together will result in the increasing trends of desertification in Asia.

10.4.4.3 Permafrosts

The permafrost thawing will continue over vast territories of North Asia under the projected climate change scenarios (Izrael *et al*., 2002). The perennially frozen rocks will completely degrade within the present southern regions of North Asia. In northern regions, mean annual temperature of frozen soil and rocks and the depth of seasonal thawing will increase (Fig. 10.5). The change in the rock temperature will result in a change in the strength characteristics, bearing capacity, and compressibility of the frozen rocks, thaw settlement strains, frozen ground exploitability in the course of excavation and mining, generation of thermokarst, thermal erosion and some other geocryological processes (Climate Change, 2004). While the changes in physical properties can have some negative effects on infrastructure, the major threshold occurs when permafrost starts to thaw from its top down. These conclusions are in good agreement with ch. 15 “Polar Regions” sections 15.1 “Executive summary” and .5.2 “Current sensitivity/vulnerability”.

The most significant impacts on ecosystems, infrastructure, carbon cycle and hydrology will be observed in areas where permafrost contains a considerable amount of ground ice in the upper few meters. Permafrost degradation will lead to significant ground surface subsidence and pounding (Osterkamp *et al*., 2000; Jorgenson *et al*., 2001). Permafrost thawing on well-drained portions of slopes and highlands in Russia and Mongolia will improve the drainage conditions and lead to a decrease in the ground water content (Hinzman *et al*., 2003; Batima *et al*., 2005b). Changes in the active layer thickness and permafrost continuity will affect ground water and river runoffs. On Tibetan Plateau, in general, permafrost zone is expected to decrease in size, move upward and face degradation by the end of this century (Wu *et al*., 2001). For a rise in surface temperature of 3^{o}C and no change in precipitation, most Tibetan Plateau glaciers of shorter than 4 km in length are projected to disappear and the glacier areas will reduce by more than 60% in the Changjiang Rivers source region by the end of this century (Shen *et al*., 2002).

10.4.5 Human health

Health outcomes in response to climate change are currently the subject of intense debate. Studying the impact of climate variability and climate change on human health requires appropriate specification of the meteorological “exposure”. Climate change is one of several concurrent environmental changes (*e.g*., urban air quality) that simultaneously affect human health – often

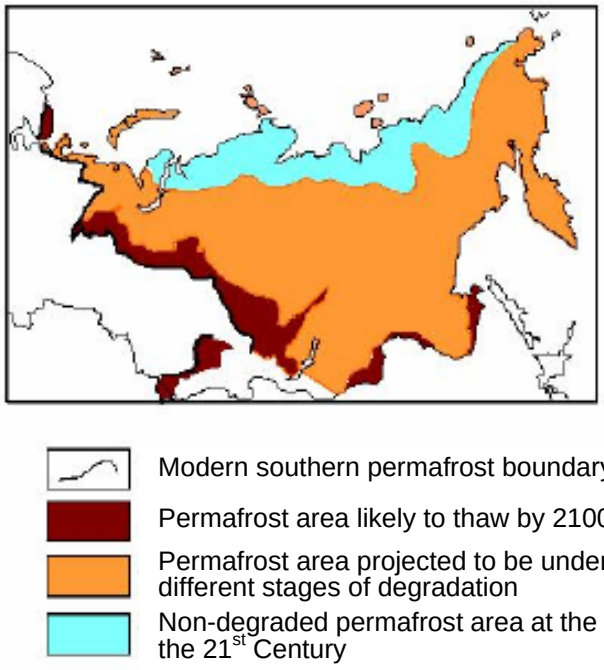

Fig. 10.5: *The projected shift of permafrost boundary in North Asia due to climate change by 2100*

interactively. The pattern of transmission of vector-borne infectious diseases in relation to climatic conditions, population movement, forest clearance and land-use patterns, biodiversity losses (*e.g.*, natural predators of mosquitoes), freshwater surface configurations, and human population density needs to be examined. A better understanding of the interaction among climate change, environmental and health status in communities at regional and local scales is crucial to forge physiological acclimatization and social adaptation.

Climate change poses substantial risks to human health in Asia. Global burden of climate-change-attributable diarrhea and malnutrition are already the largest in Southeast Asian countries including Bangladesh, Bhutan, India, Maldives, Myanmar and Nepal in 2000, and the relative risks for these conditions for 2030 is expected to be also the largest (Patz *et al*., 2005), although in some areas such as southern states in India there will be reduction in transmission season by 2080 (Mitra *et al*., 2004). An empirical model projected that the population at risk of dengue fever (the estimated risk of dengue transmission is greater than 50%) will be larger in India and China (Hales *et al*.., 2002). Also in India and China, the excess mortality due to heat stress is projected to be very high (Takahashi *et al.*, 2006), although this projection did not take into account possible adaptation and population change. There is already evidence of widespread damage to human health by urban air quality and enhanced climate variability in Asia. Throughout newly industrialized areas in Asia, such as Chongqing, China and Jakarta, Indonesia, air quality has deteriorated significantly and contributed to widespread heat stress and smog induced cardiovascular and respiratory illnesses in the region (WHO, 2004).

Negative influence of temperature anomalies on public health has been established in Russia (Climate Change and Public Health in Russia in the 21st Century, 2004). Exposure to higher temperatures appears to be a significant risk factor for cerebral infarction and cerebral ischemia during the summer months (Honda *et al*., 1995). Natural habitats of vector-borne diseases are reported to be expanding (Climate Change and Public Health in Russia in the 21st century, 2004). Prevalence of malaria and tick-borne encephalitis has also increased over time in Russia (Yasukevich *et al*., 2004; Matuschenko *et al*., 2004). The distribution of vector-borne infectious diseases such as malaria is influenced by the spread of vectors and the climate dependence of the infectious pathogens. There are reports on the possible effects of pesticide resistance of a certain type of mosquito on the transition of malaria type

(Singh *et al*., 2004). The insect-borne infectious diseases strongly modulated by future climate change include malaria, schistosomiasis, dengue fever and other virus disease (Kovats *et al*., 2003). Oncomelania is strongly influenced by climate and the infection rate of schistosomiasis is the highest in temperature range of 24^{o}C to 27^{o}C. Temperature can directly influence the breeding of malaria protozoa and suitable climate conditions can intensify the invasiveness of mosquito (Tong *et al*., 2000). A warmer and more humid climate would be favourable for propagation and invasiveness of infectious insect vector. Serious problems are connected with the impact of air pollution due to Siberian forest fires on human health (Rachmanin, 2004).

Warmer sea surface temperatures along coastlines of South and Southeast Asia would support higher phytoplankton blooms. These phytoplankton blooms are excellent habitats for survival and spread of infectious bacterial diseases such as cholera (Pascual *et al*., 2002). Water-borne diseases including cholera and the suite of diarrhoeal diseases caused by organisms such as giardia, salmonella and cryptosporidium could also become common with the contamination of drinking water quality. Precipitation increase and frequent floods, and sea level rise in future will deteriorate the surface water quality owing to more pollution, and hence lead to more water-borne infectious diseases such as dermatosis, cardiovascular disease and gastrointestinal disease. For preventive actions, impact assessments are necessary on the various aspects such as nutritional situation, drinking water supply, water salinity and ecosystem damage. The risk factor of diseases will depend on improved environmental sanitation, the hygienic practice and medical treatment facilities.

10.4.6 Human dimensions

10.4.6.1 Climate extremes and migration

In Asia migration remains dominant, providing for 64% of urban growth (Pelling, 2003). Total population, international migration and refugees in Asia and the Pacific region currently are estimated to be 3,307 million, 23 million, and 4.8 million respectively (UN-HABITAT, 2004). Future climate change is expected to have considerable impacts on natural resource systems, and it is well-established that changes in the natural environment can affect human sustenance and livelihoods. This in turn can lead to instability and conflict, often followed by displacements of people and changes in occupancy and migration patterns (Barnett, 2003).

Climate-related disruptions of human populations and consequent migrations can be expected over coming decades. Such climate-induced movements can have effects in source areas, along migration routes and in the receiving areas, often well beyond national borders. Periods when precipitation shortfalls coincide with adverse economic conditions for farmers (such as low crop prices) would be those most likely to lead to sudden spikes in rural-to-urban migration levels in China and India. Climatic changes in Pakistan and Bangladesh would likely exacerbate present environmental conditions that give rise to land degradation, shortfalls in food production, rural poverty and urban unrest. Circular migration patterns such as those punctuated by shocks of migrants following extreme weather events could be expected. Such changes would likely affect not only internal migration patterns, but also migration movements to other western countries.

Food can be produced on currently cultivated land if sustainable management and adequate inputs are applied. Attaining this situation would also require substantial improvements of socioeconomic conditions of farmers in most Asian countries to enable access to inputs and technology. Land degradation, if continued unchecked, may further exacerbate land scarcities in some countries of Asia. Concerns for the environment as well as socioeconomic considerations may infringe upon the current agricultural resource base and prevent land and water resources from being developed for

agriculture (Tao *et al*., 2003b). The production losses due to climate change may drastically increase the number of undernourished in several developing countries in Asia, severely hindering progress against poverty and food insecurity (Wang, *et al*., 2006).

10.4.6.2 Urban development, infrastructure linkages, Industry and Energy

The compounding influence of future rises in temperature due to global warming, along with increases in temperature due to local urban heat island effects, makes cities more vulnerable to higher temperatures than would be expected due to global warming alone (Kalnay *et al*., 2003; Zhou *et al*., 2005; Patz *et al*., 2005). Existing stresses in urban areas include crime, traffic congestion, compromised air and water quality, and disruptions of personal and business life due to decaying infrastructure. Climate change is likely to amplify some of these stresses, although all the interactions are not well understood. For example, it has been suggested that climate change will exacerbate the existing heat island phenomenon in cities of Japan by absorbing increased solar radiation (Shimoda, 2003). This will lead to further increases in temperatures in an urban microclimate with negative implications for energy and water consumption, human health and discomfort, and local ecosystems. Vulnerabilities and dynamics of urban infrastructures in megacities of Asia to long term impacts of projected climate change need to be worked out in terms of energy, communication, transportation, water run-off, and water quality, as well as the interrelatedness of these systems, and implications for public health (WHO, 2003).

The direct impact of global warming on industry and energy at the level currently projected from climate fluctuations and changes (significance, speed, time period) is expected to be small because such impact will be handled by unutilized capacity to meet changing demands and long-term facility renewal to deal with changing supply. However, in a country such as Japan that depends on overseas sources for about 80% of its energy and 60% of its food, it is impossible to predict the size and complexity of secondary and tertiary impacts of global warming. In a study on assessment of impacts of future climate change on ski industry following a relationship between daily snow depth and number of skiers in seven ski areas of Japan, Fukushima *et al*. (2002) reported more than 30% drop in visiting skiers in almost all ski areas in Japan except northern region (Hokkaido) and / or high altitude regions (centre of the Main Island) in the event of a 3^{o}C increase in air temperature.

If the mean June–August temperature rises by 1°C in Japan, consumption of summer products such as air conditioners, beer, soft drinks, clothing, electricity are projected to increase about 5% (Harasawa *et al*., 2003). Table 10.7 lists a summary of impacts on global warming on industries and energy sectors identified in Japan.

Table 10.7: *A summary of impacts on global warming on industries and energy sectors identified in Japan*

Changes in Climate parameters	Impacts
1^{o}C temperature increase in June to August	About 5% increase of consumption of summer products
Extension of high temperature period	Increase of consumption of air conditioners, beer, soft drinks, ice creams
Increase in Thunder storms	Damage on information devices and facilities
1^{o}C temperature increase in Summer	Increase in electricity demand by about 5 million kW Increase in electricity demand in factories to enhance production
Increase in annual average temperature	Increase of household electricity consumption in southern Japan Decrease in total energy consumption for cooling, warming in northern Japan
Change in amount and pattern of rainfall	Hydro electric power generation, management and implementation of dams, cooling water management
1^{o}C increase in cooling water temperature	0.2 – 0.4% reduction of generation of electricity in thermal power plants, 1 －2% reduction in nuclear power plant

South Asia is expected to account for one-fifth the world's total energy consumption by the end of 21st century (Parikh *et al*., 2004). Among various components, coal would continue to contribute till the middle of the 21st century while biomass will lose its share steadily. Gas, electricity, district heating and methanol would grow in shares only during the later half of the 21st century. A complete reversal in sectoral shares is expected during this period when, the industrial sector is to take over while the non-commercial sector is likely to be eliminated. The residential and transport sectors' energy consumption is also expected to increase significantly. South Asia is projected to emerge as the largest energy sector investment market in the world well before the end of this century. The investment requirements for this sector are likely to increase by more than fifteen-fold in the least, by the end of 21st century. However, the investments to GDP ratio show a decline over the years, indicating energy intensity improvements and continuous progress along technological learning curves. Among various sectors, the electricity sector calls for the highest investments, estimated between 40% and 60% of total energy sector investments by 2100. In order to meet the growing demand, primary resource extractions are also expected to increase in the region. Environmental emissions are expected to follow suit. As with the increasing trends in energy consumption, CO_2 emission of South Asia would account for about one-fifth of world's total by 2100.

10.4.6.3 Financial aspects

The financial community is awakening to the fiscal dimensions of the risk of climate change. According to the European insurer Munich Re, the annual cost of climate change related claims could reach $300 billion annually by 2050. Another major insurer, Swiss Re, no longer provides liability coverage for climate change related claims to companies that lack climate change policies. The cost of direct damage in Asia caused by tropical cyclones has increased more than 5 times in the 1980's as compared with those in the 1970's and about 35 times more in the early 1990's than in 1970's (Yoshino, 1996). In case of flood related damages, these are about 3 times and 8 times respectively in 1990s relative to those in 1980s and in 1970s. The damage caused by natural hazards has also been increasing significantly in the high GNP countries of Asia since the 1990's. International Federation of Red Cross and Red Crescent Societies (IFRCRCS, 2004) has recently brought out a report on the magnitude of vulnerability of Asian continent (in terms of loss of human life as well as on the economy) to the natural disasters (TERI,1996).

The frequency and intensity of climate related extreme events are likely to increase in the future leading to amplified economic damages in the Asia region. The Association of British Insurers have examined the financial implications of climate change through its effects on extreme storms (hurricanes, typhoons, and windstorms) using an insurance catastrophe model (ABI, 2005). Annual insured losses from the three major storm types affecting insurance markets (hurricanes in United States, typhoons in Japan and windstorms in Europe) are projected to increase by two-thirds to US$27 billion by the 2080s. The projected increase in insured losses due to even the most extreme storms (with current return periods of 100 to 250 years) by the 2080s would be more than twice the reported losses of the 2004 typhoon season, the costliest in terms of damage during the past 100 years. The insurance industries as well as society would be adversely impacted due to extreme climatic events in Asia.

10.4.6.4 Social Vulnerability

Social vulnerability is the exposure of groups of people or individuals to stress as a result of the impacts of environmental change including climate change (Adger, 2000) Social vulnerability emphasizes the inequitable distribution of damages and risks amongst groups of people (Wu *et al.*,

2002). Vulnerability is a result of social processes and structure that constrain access to the resources that enable people to cope with impacts (Blaikie *et al.*, 1994). The protection from the social forces that create inequitable exposure to risk is as, or even more, important than structural protection from natural hazards (Hewitt, 1997). An approach based on social vulnerability focuses attention on the societal factors that determine the capacity to cope, response and adapt to stress, rather than the potential hazard itself. Many developing countries of Asia are rich in natural resources and have vast potential for economic development. However, these nations remain agrarian societies and are deeply susceptible to climate variability and climate change.

The rapidly urbanizing cities of Asia today present unprecedented concentrations of poverty, and in so doing mark new levels of vulnerability. Poverty is identified as the largest barrier to developing the capacity to cope and adapt (Ninh *et al*., 2005). Poor people are forced to live in hazardous areas of the margins of urban areas where there is risk of current and future possible floods (Adger, 2003). In order to reduce social vulnerability of societies to cope with climate related disasters in developing countries of Asia, a macro-economic analyses of development programs should be carried out while the human and physical infrastructure are enhanced. Livelihoods and income security of older persons and empowerment of marginalized groups must be ensured with better management of the expectations of the population. The life-styles, consumption patterns, family planning and equity issues are eventually shifting to the centre of the climate change debate and perhaps will provide a framework of possible solution for the poor societies in Asia.

10.5 Adaptation: Sector specific practices, options and constraints

10.5.1 Agriculture and food security

The ability of agriculture to adapt to and cope with climate change in Asia will depend on factors such as population growth, poverty and hunger, availability of arable land and water resources, farming technology and access to inputs, crop varieties adopted to local conditions, access to knowledge, infrastructure, agricultural extension services, marketing and storage systems, rural financial markets, and economic status. Vulnerable populations in developing countries of Asia have only limited capacity to protect their food production system from extreme events such as droughts and floods (FAO, 2003). The developing countries of Asia bear the brunt of the consequences of climate variability and climate change. In the short term, policy makers will need to cope with an increased risk of frequent shocks to their economies, which will affect the welfare of their most vulnerable populations. Over the long term, they will need to manage the effects of climate change on the underlying production structures of the economies.

Many studies (Parry, 2002; Droogers, 2004; Lin *et al*., 2004; Vlek *et al*., 2004 Zalikhanov, 2004; Batima *et al*., 2005) on impacts of climate change on agriculture and possible adaptation options have been published since the TAR. As system vulnerability will vary in magnitude, the ability of local populations to adapt their production systems to cope with climate change will vary across Asia. They are both controlled by the flexibility with which food provision as the supply, availability and access to food and related essential resources is mediated by government institutions and policies. More common adaptation measures than have been evaluated in above-mentioned studies are summarized in Table 10.8.

Table 10.8: *Adaptation measures in Agriculture*

Sectors	Adaptation measures
Agricultural Cropping	Choice of crop and cultivar: • Use of more drought-tolerant crop varieties • Use of more disease and pest tolerant crop varieties • Use of salt- tolerant crop varieties • Introduce higher yield, earlier maturing crop varieties in cold regions Farm management: • Altered application of nutrients/fertilizer • Altered application of insecticide/pesticide • Change planting date to effectively use the prolonged growing season and irrigation practices • Develop adaptive management strategy at farm level
Livestock Production	• Breeding greater tolerance and productivity livestock • Increase stocks of forages for unfavorable time periods. • Improve Pasture and grazing management including improved grasslands and pastures. • Improve management of stocking rates and rotation of pastures • Increase the quantity of forages used to graze animals • Plant native grassland species because native species are better adapted to survival in extreme climate conditions • Increases plant coverage per hectare • Need local specific support in supplementary feed and veterinary service
Fishery	• Breeding fish to high water temperature • Fisheries management capabilities to cope with impacts of climate change must be developed
Development of Agricultural Bio-Technologies	• Development & distribution of more drought, disease, pest salt-tolerant gene into crop varieties • Develop improved processing and conservation technologies in livestock production varieties • Improve crossbreeds of high productivity animals
Improvement of Agricultural Infrastructure	• Improve pasture water supply • Improve and wide spread of irrigation systems and improve the efficiency • Improve use/store of rain and snow water • Improve information exchange system on new technologies at national as well as region and international level • Improve/develop sea defence and flood management • Equip herders, fisheries and farmers with communication system to get weather forecasts in time

Maintenance time for grassland should be settled according to the actual environmental conditions, and a reasonable rotational grazing could ensure the sustainability of grassland resources (Wang *et al*., 2004a Measures as increasing material input, changing the year-round grazing manner and increasing crop fodder supply have been proposed as effective ways for maintaining and protecting grasslands (Li *et al*., 2002; Batima *et al*., 2005). Regulations of rice varietal disposition, improvement of irrigation system, double rice breeding and introducing new rice varieties could keep productivity against risk due to climate change (Ge *et al*., 2002).

Integrating fisheries and aquaculture management into coastal areas management is critical to ensure that fisheries and aquaculture needs are taken up when dealing with protection of coastal areas from sea level rise (Troadec, 2000), which is important for small communities in East, South and Southeast countries of Asia.

One of important and effective adaptation measures is raising education level and disseminating climate change findings to the public, especially for the high illiteracy areas of Asia.

10.5.2 Hydrology and water resources

10.5.2.1 Water scarcity and water management

In some parts of Asia, conversion of cropland to forest (grassland), restoration and reconstruction of vegetations, improvement of the tree and herb varieties, selection and cultivation of new drought resistant varieties are effective measures to prevent water scarcity from climate change. Water saving schemes for irrigation should be enforced to avert the water scarcity in regions already under water stress (Wang, 2003).

Given the magnitude of projected climate change in North Asia, adaptation options to avert water scarcity include:

(a) The measures:
- to increase the power of recycling water supply systems and autonomous water use systems in industry sector;
- to use purified municipal waste waters in some industrial brunches (Frolov *et al*., 2004) and
- if necessary, cut water intake for industry needs during dry years;

(b) Measures to remove the losses of irrigation waters by increasing the efficiency of irrigation canals and systems while changes in the crop structure in favour of drought-resistant crops would be beneficial (Alcamo *et al*., 2004);

(c) The power production at hydroelectric stations would have to be compensated by other (e.g. fossil fuel) power plants (Kirpichnikov *et al*., 2004);

(d) Creation of the most favourable conditions for river fleet with depths providing the use of all available vessel types for full freight-carrying capacity during the entire navigation period – the options for optimal depths would include deepening / dredging work along the navigating channel and/or reducing the carrying capacity of ships (Golitsyn *et al*., 2002).”

10.5.2.2 Water management including infrastructures

Climate change would add to the problem of water scarcity in many countries of Asia and increasing negative impact on aquatic ecosystems and groundwater resources due to excessive water abstraction. Modernization of existing irrigation schemes and demand management aimed at optimizing physical and economic efficiency in the use of natural water resources and recycled water in water stressed countries of Asia is essential. Public investment policies aimed at improving access to available water resources should also be based on integrated water management, respect for the environment and as an important element promote better practices for wise use of water in agriculture, including recycled waste water. Scenarios for future development e.g. in the areas of irrigation, drought management, desalination, urban needs and tourism must be prepared in developing countries of Asia.

10.5.2.3 Recycling, reuse and conservation technologies

As an adaptation measure, apart from meeting non-potable water demands, recycled water can be used for recharging ground water aquifers and augmenting surface water reservoirs. Recycled water can also be used to create or enhance wetlands and riparian habitats. While water recycling is a sustainable approach towards adaptation to climate change and can be cost-effective in the long term, the treatment of wastewater for reuse such as that being practiced in Singapore now and the installation of distribution systems can be initially expensive compared to such water supply alternatives as imported water or ground water but are potentially important adaptive options in many countries of Asia. Institutional barriers, as well as varying agency priorities, can make it difficult to implement water recycling and wastewater reuse projects. But as water demands grow and environmental needs become compelling, water recycling will have to play a greater role in our overall water supply. By working together to overcome obstacles, water recycling and wastewater reuse, along with application of water conservation technologies, can help many Asian countries to conserve and sustainable manage its vital water resources when water stress becomes more severe due to climate change in future.

10.5.3 Coastal and low lying areas

The response to sea level rise could mean protection, accommodation and retreat. As substantial socio-economic activities and population are currently highly concentrated in the coastal zones in Asia, protection should remain as key focus area in Asia. Coastal protection constructions in Asia for 5-year to 1000-year storm surge elevations need to be considered. Most mega cities of Asia located in coastal zones need to ensure that future constructions are done at elevated levels (Nishioka *et al*., 1998; Du *et al*., 2000; Nicholls, 2004). The dike heightening and strengthening has been identified as one of the adaptation measure for coastal protection (Du *et al*., 2000; Huang *et al*., 2000; Li *et al*., 2004a, b).

Integrated Coastal Zone Management (ICZM) provides an effective coastal protection strategy to maximize the benefits provided by the coastal zone and to minimize the conflicts and harmful effects of activities on social, cultural and environmental resources to promote sustainable management of coastal zones (World Bank, 2002). ICZM concept is being embraced as a central organizing concept in the management of fishery, coral reef, pollution, mega cities and individual coastal systems in China, India, Indonesia, Japan, Korea, Philippine, Sri Lanka, Vietnam and Kuwait. It has been successfully applied for prevention and control of marine pollution in Batangas Bay of Philippines and Xiamen of China over the past few years (Chua, 1999; Xue *et al*.., 2004). The ICZM concept and principle may be adopted for coastal prevention and management in other countries of Asia.

10.5.4 Natural ecosystems and biodiversity

The probability of significant adverse impacts of climate change on Asian forests is high in the next few decades (Isaev *et al*., 2004). Plantation technologies should be used in developing concrete forestry adaptive options as well as in choosing locations for reforestation projects to avoid negative impact on Siberian forests. At the same time, prevention of forest from fire disaster, insects and diseases must be strengthened for sustainable development.

Programs to control deforestation and degradation in Asia must be accompanied by measures of increase agricultural productivity and sustainability. Adaptation and mitigation measures for Asia against climate change include extending rotation cycles, reducing damage to remaining trees, reducing logging waste, implementing soil conservation practices, and using wood in a more carbon-efficient way such that a large fraction of their carbon is conserved.

10.5.5 Human health

Malaria and dengue fever are among the most important vector-borne diseases in parts of Asia. Encephalitis is also becoming a public health concern. Unprecedented population growth, increased human mobility and lack of mosquito control have contributed to epidemic activity. Health risks due to climatic changes will differ between countries of Asia depending upon the infrastructure availability. Human settlement patterns in the different regions of Asia will influence disease trends. Climatic anomalies such as floods and droughts associated with ENSO and the resulting detectable influence on marine and terrestrial pathogens, including coral diseases, oyster pathogens, crop pathogens, Rift Valley fever and human cholera in Asia could have far-reaching consequences on all life-support systems. It is therefore a factor that should be placed high among those that affect human health and survival.

Assessment of the impact of climate change is the first step for exploring adaptation strategy. The disease monitoring system is essential as the basic data source. Specifically, the monitoring of diseases along with related ecological factors is required because the relation between weather factors and vector-borne diseases are complicated and delicate (Kovats *et al*., 2003). Also, disease monitoring is necessary in assessing the effectiveness and efficiency of the adaptation measures (Wilkinson *et al*., 2003). For effective adaptation measures, the potential impacts of climate variability and change on human health must be identified, along with barriers to successful adaptation and the means of overcoming such barriers.

The heat warning/warning system in the U.S. was evaluated to be effective (Ebi *et al*., 2004). Also, the similar system was operated in Shanghai, China (Tan *et al*., 2004). This type of heat warning/watch system should therefore be implemented in other areas of Asia.

10.5.6 Human dimensions

Rapid population growth, urbanization and weak land-use planning and enforcement are some of the reasons why poor people move to fragile and high risk areas which are more exposed to natural hazards. Moreover, the rapid growth of industries in urban areas has induced rural–urban migration. Rural development together with networking and advocacy, and building alliances among communities is a prerequisite for reducing the migration of people to cities and coastal areas in most developing countries of Asia (Kelly *et al*., 2000). Raising awareness about the dangers of natural disasters including those due to climate extremes is also crucial among the governments and people so that mitigation and preparedness measures could be strengthened. Social capital has been paid attention to build adaptive capacity (Allen, 2006). For example, a community based disaster management was introduced to reduce vulnerability and to strengthen people's capacity to cope with hazards by the Asian Disaster Preparedness Centre, Bangkok (Pelling, 2003).

Financial institutions have begun dealing in "climate derivatives" to compensate enterprises for loss due to extreme weather events. Such events have a large impact on the medium scale enterprises, the travel and tourism industries, and ski area and lodge operators. To minimize climate related risk, an insurance system using market mechanisms is being investigated by industry as an adaptive measure. A serious impact on the ski industry could be anticipated due to global warming. In the areas where the snow conditions would seriously deteriorate, planning should begin on the development of new industries more resistant to or suited to a warmer atmosphere, thus avoiding excessive reliance on the ski industry. New leisure industries, e.g., grass-skiing, hiking, residential lodging, eco-tourism could be considered to

compensate for the income decrease due to snow deterioration (Fukushima *et al*., 2002).

The risks of heat stress are most pronounced in large cities due to urban heat island effect in summer (Kalnay *et al*., 2003; Zhou *et al*., 2004). Planners should be aware of the health relevance of the urban climate and how innovative planning could improve the health of those living there. Appropriate urban planning should have the following objectives:

- reducing the heat island in summer;
- reducing the heat load on buildings;
- diminishing the problem of high night-time indoor temperature; and
- taking climate change into account in planning new districts and buildings and in setting up new regulations on building and urban development.

Several measures can be taken to reduce the heat load to which an individual is exposed in a city, such as planting trees or building houses with arcades that provide shade. Planners should therefore consider allowing cool air from the surroundings to penetrate the dwelling units at night by maintaining ventilation paths (Shimoda, 2003). The passive cooling technologies, which maintain indoor thermal comfort without air-conditioners or which reduce the cooling load, including reflective surfaces, the control of solar radiation by vegetation and blinds, earth tubes, the formation of air paths for natural ventilation, and rooftop planting should be promoted.

10.5.7 Key constraints

Due to the specific natural and social economic conditions of Asia, the key constraints for adaptation to climate change and climate variability come mainly from three aspects. Firstly, the natural constraints include diversified/complicated natural conditions, frequent extreme weather/climate events, and fragile environmental conditions/background, which becomes more complex due to climate change and climate variability in Asia, and results in larger spatial and temporal differences. The second aspect is socioeconomic constraints. Lower economic development level in Asia causes constraints for adaptation to climate change and climate vulnerability. At the same time, inequality to access resources makes the constraints more seriously. The constraints include lack of knowledge on interconnections between adaptation and mitigation options and insufficient knowledge to identify positive and negative impacts of climate change. For example, climate change could have some beneficial impacts for the cold regions such as North Asia and North East China. Lack of knowledge also includes weak public awareness and lag of scientific lore. Future impacts of climate change have not been assessed with precise accuracy in some regions and sectors. Lower economic development level in Asia also produces constraints of lower adaptive capacity and lower social welfare, such as insufficient investment in infrastructure and not enough investment in technology development. Lack of appropriate policy approaches also limit the response options. At the moment, in Asian countries, there are few specific policies for climate change adaptation, which results in lack of flexible adaptation processes and comprehensive adaptation. Many other policy issues currently prevent the policymakers and the public to think about adaptation.

10.6 Case Studies

10.6.1 Megadeltas in Asia

In Asia, rivers surrounding the Tibetan Plateau contribute ~50% of the world's total river-borne sediments to the ocean (Milliman *et al*., 1983) and 11 mega deltas with an area greater than 10,000 km^2 are formed in the coastal zone of Asia (Penland *et al.*, 2005), which are located in different

climate zones (Table 10.9). These megadeltas are usually populous except the Lena delta in North Asia. Seven mega cities in Asian delta region will have population exceeding 10 millions by 2010, covering 46% of the Asia's total (Nicholls, 1995; Woodrofe *et al.*, 2005). The deltas are also usually economically more developed. For instance, GDP of the Changjiang delta in 2003 is 19.5% of the China's total and the GDP of the three metropolitans located in the Zhujiang delta, Changjiang delta and Huanghe (active and old) delta will represent 80% of China's total GDP in 2050 (Niou, 2002; She, 2004; Sit *et al.*, 2004).

Ground subsidence has been found in most megadeltas, particularly in economic developed and populous mega-cities, such as Bangkok in the Chao Phraya delta, Shanghai in the Changjiang delta, Tianjin in the old Huanghe delta, which becomes a element of local relative sea level rise and exacerbates coastal flooding in megadeltas (Nguyena *et al.*, 2000; Li *et al.*, 2004; Li *et al.*, 2005; Woodrofe *et al.*, 2005; Jiang *et al.*, 2005).

The ecosystems in the mega delta wetlands are various depending on climatic zones where they are located. The wetland in the Lena delta is covered by the polar desert and Tundra vegetation dominated by low growing woody shrubs (ACIA, 2004). Wetlands in deltas of the temperate climatic zone are characterized by reed and salt-marsh grasses. In the wetlands of the deltas in South and Southeast Asia, mangrove forests are usually present and their types vary with climate conditions (Macintosh, 2005; Sanvanville *et al.*, 2005). For instance, in the Indus delta the largest arid-climate mangrove forests in the world (1600 $km^{2)}$ are found (IUCN, 2003) whereas wetlands in the Shatt Al-Arab delta are covered by widespread Sabkha, with crusts of sodium chloride and gypsum owing to arid climate and high salinity in the Persian Gulf (Sanvanville *et al.*, 2005).

The mega deltas of Asia are vulnerable to climate change and sea-level rise, particularly to exteme climate events. The Lena delta located in the boreal zone and sensitized to climate warming has been retreating at a rate of 3.6-4.5 m/a due to thermo-erosion processes (Leont'yev, 2004). Over the last 2000 years, the megadeltas fed by rivers originating from Tibetan Plateau have progradated tens even hundred kilometers (Woodrofe *et al.*, 2005) and have annually extended more than ten square kilometers in average during the last tens years, with local erosion due to sediment starvation (Thanh *et al.*, 2004; Li *et al.*, 2004; Shi *et al.*, 2005). Many of Asian megadeltas are subjected to inundation due to storm surges and floods from river drainage, such as the Deltas of the Zhujiang, the Red-River, the Ganges-Brahmaputra (Nicholls, 2004; Woodrofe *et al.*, 2005). The saltwater intrusion impacts on water supply in the Changjiang delta and Zhujiang delta, and deteriorates mangrove forests and decreases its diversity, and reduces agriculture production and freshwater fish catch, resulting in the economic loss of US$125x 10^6 per annum in the Indus delta (Huang *et al.*, 2004; Shen *et al*., 2003; IUCN, 2003).

Most Asian megadeltas are extensively reclaimed due to urbanization and expansion of agricultural areas and coastal protection construction is a main adaptation measure (Du *et al.*, 2000; Woodrofe, 2005). Reclamation usually destroys the natural ecosystems in megadeltas but in turn it lends stability and protection to mega deltas against erosion from sea waves and sea level rise. The sustainability of mega deltas in Asia in a warmer climate will rest heavily on policies and programs that promote integrated and coordinated development of the mega deltas and upstream areas, balanced use and development of mega deltas for conservation and production goals, and comprehensive protection against erosion from river flow anomalies and seawater actions.

1 ***Table 10.9:*** *Mega Deltas of Asia*

Features	Lena	Huanghe-Huaihe	Changjiang	Zhujiang	Red River	Mekong	Chao Phraya	Irrawaddy	Ganges-Brahmaputra	Indus	Shatt-Arab
Area (x10^3 km^2)	43.6	36.3	66.9	10	16	62.5	18	20.6	100	29.5	18.5
Water Discharge (10^9 m^3/yr)	520	33.5	924	326	120	470	30	430	1330	185	46
Sediment load (10^6t/a)	18	849	486	76	130	160	11	260	1969	400	100
Delta growth (km^2/a)		21.0	16.0	11.0	3.6	1.2		PD50-60/a	DG-5.1km^2/a	PD30/a	
Climate zone	Boreal	Temperate	subtropical	subtropical	Tropical	Tropical	Tropical	Tropical	Tropical	Semi-arid	Arid
Mangroves (10^3km^2)	no	no	no	no		5.2	2.4	4.2	10	1.6	no
Population (x10^6)		24.9(00)	76(03)	42.3(03)	14.8(03)	12.5(03)	18.5(03)	3.5	143	1.5	
Population increase(2015)	no	18	-	176	21	21	44	15	28	45	
GDP ($\$10^9$US)		58.8(00)	274.4(03)	240.8(03)							
Mega-city	no	Tianjin	Shanghai	Guangzhou			Bangkok		Dhaka	Karachi	
Ground subsidence (m)	no	2.6-2.8	2.0-2.6	no			0.2-1.6		0,6-1.9mm/a		
SLR (cm) in 2050	10-90 (2100)	70-90	50-70	40-60						20-50	
Saltwater intrusion(km)			100		30-50	60-70			100	80	
Natural hazards			TC	TC,FD	TC,FD				TC,FD	TC,SWI	
Inundated area (10^3km^2)by SLR		21.3(0.3m)	54.5(0.3m)	5.5(0.3m)	5(1m)	20(1m)					
Coastal protection constructions	no	1/20-1/50	1/50-1/1000	1/20-1/100	Protected	Protected	Protected	Protected	Protection		Protection

2 PD - Progradation of coast; TC - Tropical cyclone; FD - Flooding; SLR – Sea level rise; SWI - Saltwater intrusion; DG - Delta growth in area; XX – Strong ground subsidence

10.6.2 The Himalayan Glaciers

Himalayan glaciers cover about three million hectares or 17% of the mountain area as compared to 2.2% in the Swiss Alps. They form the largest body of ice outside the Polar caps and are the source of water for the innumerable rivers that flow across the Indo-Gangetic plains. Himalayan glacial snowfields store about 12,000 km^3 of freshwater. About 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganga and Brahmaputra which, in turn, are the lifeline of millions of people in South Asian Countries (Pakistan, Nepal, Bhutan, India and Bangladesh). The Gangetic basin alone is home to 500 million people, about 10% of the total human population in the region.

Glaciers in the Himalaya are receding faster than in any other part of the world (see **Table 10.10** below) and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps getting warmer at the current rate. The glaciers will be decaying at rapid, catastrophic rates. Its total area will shrink from the present 500,000 to 100,000 km^2 by the year 2035.

Table 10.10: *Record of retreat of some glaciers in the Himalaya*

Glacier	Period	Retreat of Snout (meter)	Average Retreat of Glacier (meter/year)
Triloknath Glacier (Himachal Pradesh)	1969-1995	400	15.4
Pindari Glacier (Uttaranchal)	1845-1966	2840	135.2
Milam Glacier (Uttaranchal)	1909-1984	990	13.2
Ponting Glacier (Uttaranchal)	1906-1957	262	5.1
Chota Shigri Glacier (Himachal Pradesh)	1986-1995	60	6.7
Bara Shigri Glacier (Himachal Pradesh)	1977-1995	650	36.1
Gangotri Glacier (Uttaranchal)	1977-1990	364	28.0
Gangotri Glacier (Uttaranchal)	1985-2001	368	23.0
Zemu Glacier (Sikkim)	1977-1984	194	27.7

The receding and thinning of Himalayan glaciers can be blamed primarily on the global warming due to increase in anthropogenic emission of greenhouse gases. The relatively high population density near these glaciers and consequent deforestation and land use changes has also affected adversely these glaciers. The five-kilometre-long Dokriani Bamak glacier in Himachal Pradesh that feeds the Ganges retreated by 20 m in 1998 in spite of a severe winter in 1997, compared to an annual average of 16.5 m over the past five years. This is a phenomenal melt rate. The 30.2 km long Gangotri glacier, too, has been receding alarmingly in recent years. From observations dating back to 1842, the rate of recession of the snout — the point at which the glacier ice ends — has been found to increase more than two-and-a-half fold per year (Fig. 10.6). Between 1842 and 1935, the glacier was receding at an average of 7.3 m every year, whereas between 1935 and 1990, the rate of recession has gone up to 18 m a year. The average rate of recession between 1985 and 2001 is about 23 m per year (Hasnain, 2002).

Most of the rivers in northern India originate from glaciers. About 70 to 80% of the water in these rivers comes from snow and glacial melts, and the rest from monsoonal rains. The current trends of glacial melts heavily suggest that Ganga, Indus, Brahmaputra and the innumerable rivers that criss-cross the entire northern Indian plain will become seasonal rivers in the near future as a consequence of climate change and this will have implications for the economies of the countries in the region.

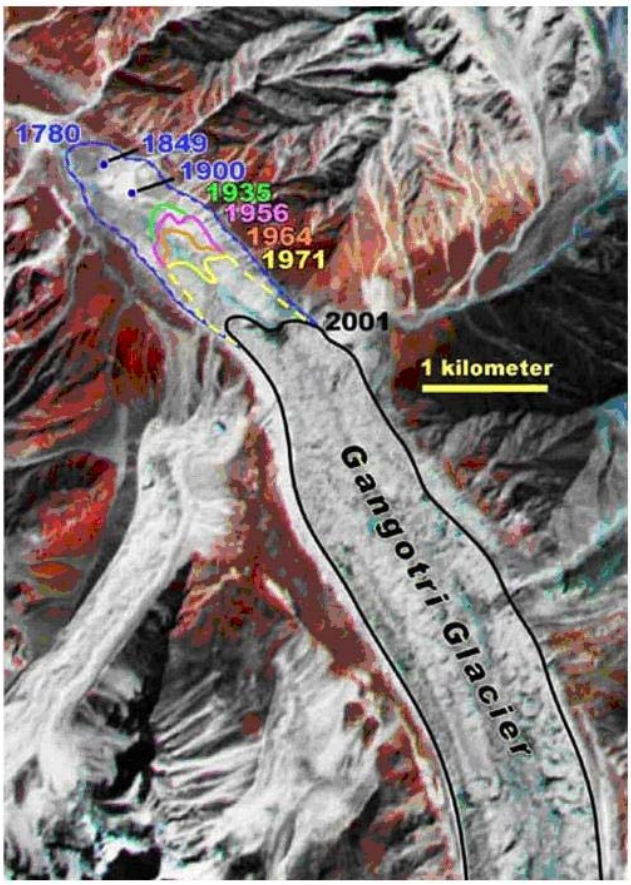

Fig. 10.6: *This composite impage from the ASTER (Advanced Spacebone Thermal Emission and Reflection Radiometer) instrument aboard NASA's Terra satellite shows how the Gangotri Glacier terminus has retracted since 1780 (courtesy of NASA EROS Data Center, Sept. 9, 2001)*

10.7 Implications for Sustainable development

Sustainable development represents a compromise between the twin goals of environmental sustainability and human economic development and suggests that these are compatible, attainable and mutually inseparable. It implies a development that drives a country's economy within the limited ability of its ecosystem to regenerate resources extracted from it for economic growth and to absorb and clean up the wastes given off by the economy that are otherwise harmful within and outside its boundary. Thus sustainable development is commonly evaluated not only in terms of social well being and intra and inter-generational equity but also in terms of environmental quality. As the socioeconomic development level is relatively low in most countries of Asia, improvements in the socioeconomic condition can strongly support to solve the environmental issues (including climate change and its adaptation). Some of the key issues and challenges related to sustainable development in Asia and its impacts on the environment include:-

- Poverty and illiteracy;
- Effective protection of environment;
- Prudent use of natural resources;
- Maintaining higher level of economic growth and equitable development;
- Role of Information and Communication Technology (ICT) in socioeconomic growth;

- People empowerment; and
- Compliance with and Governance of Multi-lateral Environmental Agreements (MEAs).

The discussion below will focus on how the above issues and challenges moderate the main drivers of environmental change (e.g., climate change, land use and land cover change, and institutional change) in Asia and support sustainable development pathways for the future.

10.7.1 Poverty and illiteracy

Majority of the Asian population are living below the poverty threshold. Coupled with illiteracy, poverty subverts the ability of the people to pursue the usually long term sustainable development goals in favour of the immediate goal of meeting their daily subsistence needs. This manifests in the way poverty drives poor communities to abusive use of land and other resources that lead to onsite degradation and usually macro scale environmental deterioration. In the absence of opportunities for engaging in stable and gainful livelihood, poverty stricken communities are left with no option but to utilize even the unproductive lands or lands that have been legally set aside for protection purposes such as conservation of biodiversity, soil and water.

10.7.2 Economic growth and equitable development

A key concern in most Asian countries is how to propel their economies to a rate of growth that will pull its poor up to alleviate the poverty where they are expected to more likely appreciate the need to protect the environment. Such concerns become more challenging when the baseline is saddled with inequitable opportunities to the disadvantage of the poor. The mere growth in economy is insufficient to achieve sustainable development goals particularly under changed climatic conditions. Moreover, as the economy grows there is a need to increase the investment on enhancing the ability of the poor to appreciate and actively participate in economic development as well as in the protection of the environment. This will include investing in building up the technical and financial readiness of the poor through training and suitable financial assistance programs.

10.7.3 ICT and socioeconomic growth

Information and Communication Technology (including internet, database and information management technologies etc.) has become a potent force in social, economic, and political life. The ICTs have a powerful role for Natural Resources Data Management System with a focus on development of spatial data management tools for local level planning for water resource management, land use planning, energy management and infrastructure development. However, the impact of ICT development oriented program can probably be judged only if it serves as a mediator of social, political and economic functions. Any development process has to ensure that it plays a transformative role for social inclusion of the marginalized sections. ICT can play a critical role in providing an enabling environment for local development and people's empowerment. ICT can provide employment opportunities; improve people's access to basic services, creating networks for disaster management, information sharing, knowledge building and increasing transparency and accountability and effectiveness of development actors. Developing Countries in Asia need to embrace ICT at both the policy and strategy levels and also with supporting bottom-up approaches that can help to ensure that national strategies are responsive, demand-driven and contribute to overall socioeconomic growth. ICT could be mainstreamed into areas such as poverty reduction, governance, decentralization, gender equity, environmental sustainability, disaster preparedness,

vulnerability reduction and adaptation to climate change through synergistic partnerships in favour of the poor and marginalized.

10.7.4 Compliance with and governance of MEAs

Multilateral environmental agreements (MEAs) are critical to the attainment of sustainable development goals in Asia. Common problem areas in Asia (i.e., biodiversity conservation and forest utilization, climate change, international water resources, overexploitation of regional fisheries, trans-boundary air pollution, and pollution of regional seas) related to sustainable development are being dealt with through several MEAs. Some of these agreements include the Framework Convention on Climate Change (FCCC), the Convention on Biological Diversity (CBD), the Convention to Combat Desertification (CCD), the Convention on International Trade in Endangered Fauna and Flora (CITES), the Ramsar Convention to protect Mangroves and Wetlands, the Montreal and Kyoto Protocols to address problems of the breakdown in the Earth's protective ozone layer and global warming, ITTO that governs the exploitation of tropical forests and conservation of biodiversity and International Convention for the Prevention of Pollution from Ships for control of pollution of Regional Seas. The major challenge for Asian countries is how to promote the adherence to and compliance with the terms and conditions of MEAs among the participating countries without unduly hampering economic development. It will require strong mechanism for monitoring the efforts of each country to implement the provisions of these agreements.

10.7.5 Prudent use of natural resources

Inherent to the concept of sustainable development is the inseparability of natural resource use and environmental protection. Thus, sustainable development pathways must employ a package of resource utilization strategies that maximize outputs and minimize wastes and damages to the ecosystems, and protection measures that complete the shield of the ecosystems against injurious agents independent of resource utilization. The challenge for most of Asia will fall greatly on countries with developing economies where the need to maximize production could outweigh the necessity to protect the ecosystems and the environment in future.

10.8 Key uncertainties, research gaps and priorities

10.8.1 Uncertainties

The base for future climate change studies is designing future social development scenarios by various models and projecting future regional and local changes in climate and its variability based on those social development scenarios so that most plausible impacts of climate change could be assessed. The emission scenarios of greenhouse gases and aerosols are strongly related to the socioeconomics of the countries in the region and could be strongly dependent on development pathways followed by individual nations. Inaccurate description on future scenarios of socioeconomic change, environmental change, land use change and technical advancement will lead to incorrect GHG emission scenarios. Future impacts of technological progress and social development on the natural system also contribute to uncertainties in assessing the impacts of climate change. Therefore factors affecting design of social development scenarios need to be examined to identify key uncertainties.

The large natural climate variability in Asia adds a further level of uncertainty in the evaluation of a climate change simulation. Our current understanding of the precise magnitude of climate change due to anthropogenic factors is relatively low due to imperfect knowledge and/or representation of physical processes, limitations due to the numerical approximation of the model's equations, simplifications and assumptions in the models and/or approaches, internal model variability, and inter-model or inter-method differences in the simulation of climate response to given forcing. Current efforts on climate variability and climate change studies increasingly rely upon diurnal, seasonal, latitudinal, and vertical patterns of temperature trends to provide evidence for anthropogenic signatures. Such approaches require increasingly detailed understanding of the spatial variability of all forcing mechanisms and their connections to global, hemispheric, and regional responses.

Uncertainty in assessment methodologies *per se* is also one of main source of uncertainty. In the model based assessments, results on impacts of climate change, in fact, accumulate errors from the methodologies for establishment of socioeconomic scenarios, environmental scenarios, climate scenarios, and climate impact assessment. A small error may be enlarged in the process of such accumulation.

10.8.2 Confidence levels and unknowns

The vulnerability of key sectors to the projected climate change for each of the six subregions of Asia based on currently available scientific literature referred to in this assessment have been assigned a degree of confidence which is listed in Table 10.11 below. The availability of water resources, food productivity and biodiversity in most of the subregions of Asia would be highly vulnerable to climate change. The potential impacts of climate change would be felt most severely in East, South and Southeast Asia. There may be some beneficial impacts of climate change in North Asia.

Some of the greatest concerns emerge not from the most likely future outcomes but rather from possible "surprises". Growing evidence suggests the ocean-atmosphere system that controls the world's climate can lurch from one state to another such as a shutdown of the 'ocean conveyor belt' in less than a decade. Due to the complexity of Earth Systems, it is possible that climate change will evolve quite differently from what we expect. Certain threshold events may become more probable and non-linear changes and surprises should be anticipated, even if they cannot be predicted with a high degree of confidence. Abrupt or unexpected changes pose great challenges to our ability to adapt and can thus increase our vulnerability to significant impacts.

Table 10.11: *Vulnerability of key sectors to the impacts of climate change by subregions in Asia*

Sub-regions	Food and Fiber	Bio-diversity	Water Resource	Coastal Ecosystem	Human Health	Settlements	Land Degradation
North Asia	+1 / H	-2 / M	+1 / M	-1 / M	-1 / M	-1 / M	-1 / M
Central Asia	-2 / H	-1 / M	-2 / VH	-1 / L	-2 / M	-1 / M	-2 / H
Tibetan Plateau	+1/ L	-2 / M	-1 / M	Not applicable	No information	No information	-1 / L
East Asia	-2 / VH	-2 / H	-2 / H	-2 / H	-1 / H	-1 / H	-2 / H
South Asia	-2 / H	-2 / H	-2 / H	-2 / H	-2 / M	-1 / M	-2 / H
Southeast Asia	-2 / H	-2 / H	-1 / H	-2 / H	-2 / H	-1 / M	-2 / H

The spotlight in climate research is shifting from gradual to rapid or abrupt change. There is some risk that a catastrophic collapse of the ice sheet could occur over a couple of centuries if polar water

temperatures warm by a few degrees. Scientists suggest that such a risk has a probability of between 1 and 5% (Alley, 2002). Because of this risk, as well as the possibility of a larger than expected melting of the Greenland Ice Sheet, a recent study estimated that there is a 1% chance that global sea level could rise by more than 4 meters in the next two centuries (Hulbe *et al.*, 2001).

10.8.3 Research gaps and priorities

In general, the level of social-economic development of countries and regions in Asia is relatively low. The current understanding of science and state of available technology cannot satisfy the requirements of global change research. A number of fundamental scientific questions relating to the buildup of greenhouse gases in the atmosphere and the behaviour of the climate system need to be critically addressed which include (a) the future usage of fossil fuels, (b) the future emissions of methane, (c) the fraction of the future fossil-fuel carbon that will remain in the atmosphere and provide radiative forcing versus exchange with the oceans or net exchange with the land biosphere, (d) details of the regional and local climate change given an overall level of global climate change, (e) the nature and causes of the natural variability of climate and its interactions with forced changes, and (f) the direct and indirect effects of the changing distributions of aerosols.

An effective strategy for advancing the understanding of adverse impacts of climate change in Asia will require strengthening the academic and research institutions to make an all-out effort to conduct innovative research at the regional or sectoral level that also promotes analysis of the response of human and natural systems to multiple stresses. Research enterprises dealing with climate change and the interactions of human society with the environment must also be enhanced.

Priorities for Asia in its quest for understanding the regional, national and local sector specific impacts of climate change and drawing up appropriate adaptation / mitigation strategies are:-

- basic physiological and ecological studies of the effects of changes in atmospheric conditions. The most pressing need over much of the region is for sound assessment and monitoring programs to establish current baselines and identify rates of change.
- capability to establish systematic observation facilities and collection and compilation of basic data;
- impacts of extreme weather events such as disasters from flood, surges storm, sea level rising, and plant diseases and insect pests;
- adaptation researches including agro-technology, water resources management, integrated coastal zone management; pathology and diseases monitoring and control;
- sectoral interaction in irrigation and water resources, agricultural land use and natural ecosystem, water resources and cropping, water resources and livestock farming, water resources and aquaculture, water resource and hydropower, sea level rise and land use, sea water invasion and land degradation; and
- identification of the critical climate thresholds for various regions and sectors to better understand the response of different systems to climate change.

In addition to the above priorities, there is need for strengthening existing cooperation among countries in Asia as also among global partners in respect of (a) improvement of information-sharing and data networking on climate change in the region, (b) collection and sharing the knowledge on climate change and its ecological, social and economical impacts in the region, and (c) developing approaches and methodology for cost-effective adaptation and mitigation strategies to minimise the impacts of climate change in the region.

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