**ASIA**

**TAR 2001**

**Asia Food**

Rice is central to nutrition in Asia. In 1997, rice provided about 700 kilocalories per person per day or more for approximately 2.9 billion people, most of whom live in developing countries of Asia and Africa. During the 1990s, rice production and productivity in Asia grew at a much slower rate than did population. Yield deceleration of rice (the annual growth rate declined from 2.8% in the 1980s to 1.1% in the 1990s) in Asia has been attributed to water scarcity, indiscriminate addition and inefficient use of inputs such as inorganic fertilizers and pesticides, and policy issues and the reliance on a narrower genetic material base with impacts on variability (Hazell, 1985; Matson et al., 1997; Naylor et al., 1997). Several other factors also have contributed to productivity stagnation and the decline of rice (lower output/input ratio) in the intensive cropping system (two to three rice crops per year). Key factors currently contributing to the yield gap in different countries of Asia include biophysical, technical/management, socioeconomic, institutional/policy, technology transfer, and adoption/linkage problems.

Urbanization in Asia has accentuated increased demand for fresh vegetables; this demand is to be met by new production areas combined with more intensified horticulture crop management to raise the productivity per unit of land and water. In most cases, urban and peri-urban agriculture initiatives with uncontrolled use of agrochemicals are a high-risk activity. Adequate steps need to be taken at regional and local levels to safeguard specialized and diversified urban production systems (vegetables, fruits, and root crops) through sustainable intensification of natural resource use and strengthening of decision support systems. Increased productivity and sustained production of food grains and legumes, industrial crops (oil, gum and resins, beverage, fiber, medicines, aromatic plants), and horticultural crops through crop diversification is critical for food and nutritional security in Asia.

Even minor deviations outside the "normal" weather range seriously impair the efficiency of externally applied inputs and food production. Moisture stress from prolonged dry spells or thermal stress resulting from heat-wave conditions significantly affect the agricultural productivity when they occur in critical life stages of the crop (Rounsevell et al., 1999).

As reported in IPCC (1998), stress on water availability in Asia is likely to be exacerbated by climate change. Several studies aimed at understanding the nature and magnitude of gains or losses in yield of particular crops at selected sites in Asia under elevated CO2 conditions and associated climatic change have been reported in the literature (e.g., Lou and Lin, 1999).

These studies suggest that, in general, areas in mid- and high latitudes will experience increases in crop yield, whereas yields in areas in the lower latitudes generally will decrease. Climatic variability and change will seriously endanger sustained agricultural production in Asia in coming decades. The scheduling of the cropping season as well as the duration of the growing period of the crop also would be affected.

In general, increased CO2 levels and a longer frost-free growing season are expected to enhance agricultural productivity in north Asia. The area under wheat cultivation is likely to expand in the north and west. The increase in surface temperature also may increase the growing season in temperate Asia, thereby prolonging the grain-filling period, which may result in higher yields (Rosenzweig and Hillel, 1998). In Japan, for example, simulation studies and field experiments indicate that enhanced CO2 levels in a warmer atmosphere will substantially increase rice yields and yield stability in northern and north-central Japan (Horie et al, 1995a). In south central and southwestern Japan, however, rice yields are expected to decline by at least 30% because of spikelet sterility and shorter rice growing duration (Matsui and Horie, 1992).

Climate change should be advantageous to wheat yield in northeast China. Because of an increase in respiration in a warmer atmosphere demanding more water availability, rice yield in China is expected to decline (Wang, 1996a). In central and north China, higher temperatures during teaseling and drawing stages and low soil moisture could result in reduced wheat yield.

Increases in precipitation should be favorable for pests, diseases, and weeds in the south (Wang, 1996b; Dai, 1997).

In tropical Asia, although wheat crops are likely to be sensitive to an increase in maximum temperature, rice crops would be vulnerable to an increase in minimum temperature.

The adverse impacts of likely water shortage on wheat productivity in India could be minimized to a certain extent under elevated CO2 levels; these impacts, however, would be largely maintained for rice crops, resulting in a net decline in rice yields (Aggarwal and Sinha, 1993; Rao and Sinha, 1994; Lal et al., 1998d).

Acute water shortage conditions combined with thermal stress should adversely affect wheat and, more severely, rice productivity in India even under the positive effects of elevated CO2 in the future.

Key findings on the impacts of an increase in surface temperature and elevated CO2 on **rice production in Asia**—based on a study carried out for Bangladesh, China, India, Indonesia, Japan, Malaysia, Myanmar, the Philippines, South Korea, and Thailand under the Simulation and System Analysis for Rice Production Project at the International Rice Research Institute—are summarized in[Table 11-5](http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=434#tab115). Two process-based crop simulation models—the ORYZA1 model (Kropff et al., 1995) and the SIMRIW model (Horie et al., 1995b)—suggest that the positive effects of enhanced photosynthesis resulting from doubling of CO2 are more than offset by increases in temperature greater than 2°C (Matthews et al., 1995a).

More than 10,000 different species of insect pest are found in the tropics, 90% of which are active in the humid tropics. The occurrence, development, and spread of crop diseases depend on integrated effects of pathogen, host, and environmental conditions. The survival rate of pathogens in winter or summer could vary with an increase in surface temperature (Patterson et al., 1999). Higher temperatures in winter will not only result in higher pathogen survival rates but also lead to extension of cropping area, which could provide more host plants for pathogens. Thus, the overall impact of climate change is likely to be an enlargement of the source, population, and size of pathogenic bacteria. Damage from diseases may be more serious because heat-stress conditions will weaken the disease-resistance of host plants and provide pathogenic bacteria with more favorable growth conditions. The growth, reproduction, and spread of disease bacteria also depend on air humidity; some diseases—such as wheat scab, rice blast, and sheath and culm blight of rice—will be more widespread in temperate and tropical regions of Asia if the climate becomes warmer and wetter.

**IPCC 2007**

**Summary of knowledge assessed in the Third Assessment Report**

**10.1.1 Climate change impacts in Asia**

***Climate change and 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 Third Assessment Report (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 (Lal et al., 2001a). The rise in surface air temperature was projected to be most pronounced over boreal Asia in all seasons.

***Climate change impacts.***

An enhanced hydrological cycle and an increase in area-averaged annual mean rainfall over Asia were projected. 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 Vulnerabilities and adaptive strategies**

*Vulnerable sectors*. 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.

*Vulnerable regions*. 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 landslides, 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 is also 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.

*Advances since the TAR*. Aside from new knowledge on the current trends in climate variability and change – including the extreme weather events – more information is now available that confirms most of the key findings on impacts, vulnerabilities and adaptations for Asia. This chapter assesses the state of knowledge on impacts, vulnerabilities and adaptations for various regions in Asia.

**10.2.3 Observed changes in extreme climatic events**

Significantly longer heatwave duration has been observed in many countries of Asia, as indicated by pronounced warming trends and several cases of severe heatwaves (De and Mukhopadhyay, 1998; Kawahara and Yamazaki, 1999; Zhai et al., 1999; Lal, 2003; Zhai and Pan, 2003; Ryoo et al., 2004; Batima et al., 2005a; Cruz et al., 2006; Tran et al., 2005).

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

**10.2.4.1 Agriculture and food production**

Production of rice, maize and wheat in the past few decades has declined in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of El Niño and reduction in the number of rainy days (Wijeratne, 1996; Aggarwal et al., 2000; Jin et al., 2001; Fischer et al., 2002; Tao et al., 2003a; Tao et al., 2004). In a study at the International Rice Research Institute, the yield of rice was observed to decrease by 10% for every 1°C increase in growing-season minimum temperature (Peng et al., 2004). A decline in potentially good agricultural land in East Asia and substantial increases in suitable areas and production potentials in currently cultivated land in Central Asia have also been reported (Fischer et al., 2002). Climate change could make it more difficult than it is already to step up the agricultural production to meet the growing demands in Russia (Izrael and Sirotenko, 2003) and other developing countries in Asia.

Generally, the frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, and debris and mud flows, while the number of rainy days and total annual amount of precipitation has decreased (Zhai et al., 1999; Khan et al., 2000; Shrestha et al., 2000; Izrael and Anokhin, 2001; Mirza, 2002; Kajiwara et al., 2003; Lal, 2003; Min et al., 2003; Ruosteenoja et al., 2003; Zhai and Pan, 2003; Gruza and Rankova, 2004; Zhai, 2004). However, there are reports that the frequency of extreme rainfall in some countries has exhibited a decreasing tendency (Manton et al., 2001; Kanai et al., 2004).

Increasing frequency and intensity of droughts in many parts of Asia are attributed largely to a rise in temperature, particularly during the summer and normally drier months, and during ENSO events (Webster et al., 1998; Duong, 2000; PAGASA, 2001; Lal, 2002, 2003; Batima, 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005).

Recent studies indicate that the frequency and intensity of tropical cyclones originating in the Pacific have increased over the last few decades (Fan and Li, 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 damage caused by intense cyclones has risen significantly in the affected countries, particularly India, China, Philippines, Japan, Vietnam and Cambodia, Iran and Tibetan Plateau (PAGASA, 2001; ABI, 2005; GCOS, 2005a, b).

**10.2.4.2 Hydrology and water resources**

In drier parts of Asia, melting glaciers account for over 10% of freshwater supplies (Meshcherskaya and Blazhevich, 1990; Fitzharris, 1996; Meier, 1998). Glaciers in Asia are melting faster in recent years than before, as reported in Central Asia, Western Mongolia and North-West China, particularly the Zerafshan glacier, the Abramov glacier and the glaciers on the Tibetan Plateau (see [Section 10.6.2](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-6-2.html)) (Pu et al., 2004). As a result of rapid melting of glaciers, glacial runoff and frequency of glacial lake outbursts causing mudflows and avalanches have increased (Bhadra, 2002; WWF, 2005). A 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).

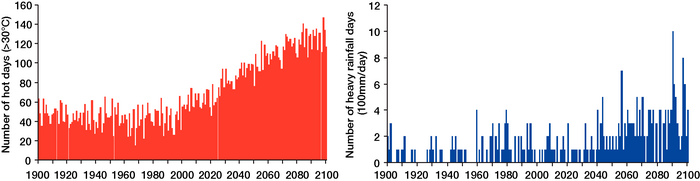
In parts of China, the rise in temperature and decreases in precipitation (Ma and Fu, 2003; Wang and Zhai, 2003), along with increasing water use have caused water shortages that led to drying up of lakes and rivers ( Liu et al., 2006; Wang and Jin, 2006). In India, Pakistan, Nepal and Bangladesh, water shortages have been attributed to rapid urbanisation and industrialisation, population growth and inefficient water use, which are aggravated by changing climate and its adverse impacts on demand, supply and water quality. In arid Central and West Asia, changes in climate and its variability continue to challenge the ability of countries in the arid and semi-arid region to meet the growing demands for water (Abu-Taleb, 2000; UNEP, 2002; Bou-Zeid and El-Fadel, 2002; Ragab and Prudhomme, 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 (Manton et al., 2001).

**10.3 Assumptions about future trends**

**10.3.1 Climate**

The consensus of AR4 models, as discussed in [Chapter 2](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch2.html) and in Christensen et al. (2007) and confirmed in several studies using regional models (Lal, 2003; Rupa Kumar et al., 2003; Kwon et al., 2004; Boo et al., 2004; Japan Meteorological Agency, 2005; Kurihara et al., 2005), indicates an increase in annual precipitation in most of Asia during this century; the relative increase being largest and most consistent between models in North and East Asia. The sub-continental mean winter precipitation will very likely increase in northern Asia and the Tibetan Plateau and likely increase in West, Central, South-East and East Asia. Summer precipitation will likely increase in North, South, South-East and East Asia but decrease in West and Central Asia. The projected decrease in mean precipitation in Central Asia will be accompanied by an increase in the frequency of very dry spring, summer and autumn seasons. In South Asia, most of the AR4 models project a decrease of precipitation in December, January and February (DJF) and support earlier findings reported in Lal et al. (2001b).

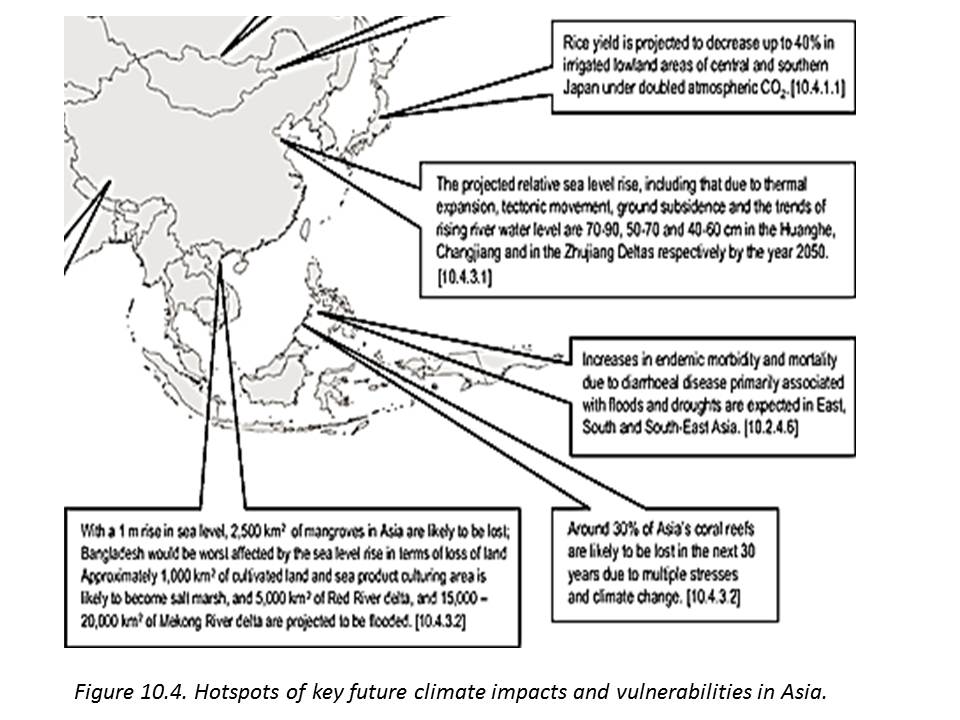
An increase in occurrence of extreme weather events including heatwave and intense precipitation events is also projected in South Asia, East Asia, and South-East Asia (Emori et al., 2000; Kato et al., 2000; Sato, 2000; Lal, 2003; Rupa Kumar et al., 2003; Hasumi and Emori, 2004; Ichikawa, 2004; May, 2004b; Walsh, 2004; Japan Meteorological Agency, 2005; Kurihara et al., 2005) along with an increase in the interannual variability of daily precipitation in the Asian summer monsoon (Lal et al., 2000; May, 2004a; Giorgi and Bi, 2005). Results of regional climate model experiments for East Asia (Sato, 2000; Emori et al., 2000; Kato et al., 2000; Ichikawa, 2004; Japan Meteorological Agency, 2005; Kurihara et al., 2005) indicate that heatwave conditions over Japan are likely to be enhanced in the future ([Figure 10.2](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/figure-10-2.html)). Extreme daily precipitation, including that associated with typhoon, would be further enhanced over Japan due to the increase in atmospheric moisture availability (Hasumi and Emori, 2004). The increases in annual temperature and precipitation over Japan are also projected regionally using regional climate model ([Figure 10.3](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/figure-10-3.html); Japan Meteorological Agency, 2005; Kurihara et al., 2005).



*Figure 10.2. Projected number of hot days (>30°C) and days of heavy rainfall (>100 mm/day) by the high resolution general circulation model (Hasumi and Emori, 2004).*

An increase of 10 to 20% in tropical cyclone intensities for a rise in sea-surface temperature of 2 to 4°C relative to the current threshold temperature is likewise projected in East Asia, South-East Asia and South Asia (Knutson and Tuleya, 2004). Amplification in storm-surge heights could 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 South-East Asian countries. The impacts of an increase in cyclone intensities in any location will be determined by any shift in the cyclone tracks (Kelly and Adger, 2000).

**10.4 Key future impacts and vulnerabilities**

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**10.4.1 Agriculture and food security**

**10.4.1.1 Production**

Results of recent studies suggest that substantial decreases in cereal production potential in Asia could be likely by the end of this century as a consequence of climate change.

However, regional differences in the response of wheat, maize and rice yields to projected climate change could likely be significant (Parry et al., 1999; Rosenzweig et al., 2001).

Results of crop yield projection using HadCM2 indicate that crop yields could likely increase up to 20% in East and South-East Asia while it could decrease up to 30% in Central and South Asia even if the direct positive physiological effects of CO2 are taken into account. As a consequence of the combined influence of fertilisation 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). In Bangladesh, production of rice and wheat might drop by 8% and 32%, respectively, by the year 2050 (Faisal and Parveen, 2004).

For the warming projections under A1FI emission scenarios (see [Table 10.5](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-3.html#table-10-5)), decreases in crop yields by 2.5 to 10% in 2020s and 5 to 30% in 2050s have been projected in parts of Asia (Parry et al., 2004). Doubled CO2 climates could decrease rice yields, even in irrigated lowlands, in many prefectures in central and southern Japan by 0 to 40% (Nakagawa et al., 2003) through the occurrence of heat-induced floret sterility (Matsui and Omasa, 2002). 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 simulation modelling studies based on future climate change scenarios indicate that substantial loses are likely in rain-fed wheat in South and South-East Asia (Fischer et al., 2002). For example, a 0.5°C rise in winter temperature would reduce wheat yield by 0.45 tonnes per hectare in India (Lal et al., 1998; Kalra et al., 2003).

More recent studies suggest a 2 to 5% decrease in yield potential of wheat and maize for a temperature rise of 0.5 to 1.5°C in India (Aggarwal, 2003).

Studies also suggest that a 2°C increase in mean air temperature could decrease rain-fed rice yield by 5 to 12% in China (Lin et al., 2004).

In South Asia, the drop in yields of 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, 2007).

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 scenario (Lal, 2007).

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).

**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 (Sukumar et al., 2003; Christensen et al., 2004; Tserendash et al., 2005). The limited herbaceous production, heat stress from higher temperature, and limited water intake due to a decrease in rainfall could cause reduced milk yields in animals and an increased incidence of some diseases.

The Asia-Pacific region is the world’s largest producer of fish, from both aquaculture and capture fishery sectors. Recent studies suggest a reduction of primary production in the tropical oceans because of changes in oceanic circulation in a warmer atmosphere. The tuna catch of East Asia and South-East Asia is nearly one-fourth of the world’s total. A modelling 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 over fishing, pollution, red tide, and other climatic and environmental pressures. The migration route and migration pattern and, hence, regional catch of principal marine fishery species, such as ribbon fish, small and large yellow croakers, could be greatly affected by global climate change (Su and Tang, 2002; Zhang and Guo, 2004). Increased frequency of El Niño events could likely lead to measurable declines in fish larvae abundance in coastal waters of South and South-East Asia. These phenomena are expected to contribute to a general decline in fishery production in the coastal waters of East, South and South-East 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 could increase productivity of fish-prey and provide more extensive habitats. In contrast, the northern shrimp will likely decrease with rise in sea-surface temperatures (ACIA, 2005).

The impact of climate change on Asian fishery depends on the complicated food chains in the surrounding oceans, which are likely to be disturbed by the climate change. Fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen, due to a rise in surface air temperatures. In the plains, the timing and amount of precipitation could also affect the migration of fish species from the river to the floodplains for spawning, dispersal and growth (FAO, 2003). Future changes in ocean currents, sea level, sea-water temperature, salinity, wind speed and direction, strength of upwelling, the mixing layer thickness and predator response 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).

**Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability**

**ASIA**

**10.4.1 Agriculture and food security**

**10.4.1.1 Production**

Results of recent studies suggest that substantial decreases in cereal production potential in Asia could be likely by the end of this century as a consequence of climate change. However, regional differences in the response of wheat, maize and rice yields to projected climate change could likely be significant (Parry et al., 1999; Rosenzweig et al., 2001).

Results of crop yield projection using HadCM2 indicate that crop yields could likely increase up to 20% in East and South-East Asia while it could decrease up to 30% in Central and South Asia even if the direct positive physiological effects of CO2 are taken into account. As a consequence of the combined influence of fertilisation 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). In Bangladesh, production of rice and wheat might drop by 8% and 32%, respectively, by the year 2050 (Faisal and Parveen, 2004). For the warming projections under A1FI emission scenarios (see [Table 10.5](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-3.html#table-10-5)), decreases in crop yields by 2.5 to 10% in 2020s and 5 to 30% in 2050s have been projected in parts of Asia (Parry et al., 2004). Doubled CO2 climates could decrease rice yields, even in irrigated lowlands, in many prefectures in central and southern Japan by 0 to 40% (Nakagawa et al., 2003) through the occurrence of heat-induced floret sterility (Matsui and Omasa, 2002). 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 simulation modelling studies based on future climate change scenarios indicate that substantial loses are likely in rain-fed wheat in South and South-East Asia (Fischer et al., 2002). For example, a 0.5°C rise in winter temperature would reduce wheat yield by 0.45 tonnes per hectare in India (Lal et al., 1998; Kalra et al., 2003). More recent studies suggest a 2 to 5% decrease in yield potential of wheat and maize for a temperature rise of 0.5 to 1.5°C in India (Aggarwal, 2003). Studies also suggest that a 2°C increase in mean air temperature could decrease rain-fed rice yield by 5 to 12% in China (Lin et al., 2004). In South Asia, the drop in yields of 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, 2007). 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 scenario (Lal, 2007). 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 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 (Tserendash et al., 2005). Studies suggest that by the middle of this century in northern China, tri-planting boundary will likely shift by 500 km from Changjiang valley to Huanghe 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 could marginally increase in the Russian Federation and in East Asia (Fischer et al., 2002).

More than 28 Mha in South and East Asia require a substantial increase in irrigation for sustained productivity (FAO, 2003). Agricultural irrigation demand in arid and semi-arid regions of Asia is estimated to increase by at least 10% for an increase in temperature of 1°C (Fischer et al., 2002; Liu, 2002). The rain-fed crops in the plains of North and North-East China could 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).

As land for agriculture becomes limited, the need for more food in South Asia could likely be met by increasing yields per unit of land, water, energy and time, such as through precision farming. Enhanced variability in hydrological characteristics will likely continue to affect grain supplies and food security in many nations of Asia. Intensification of agriculture will be the most likely means to meet the food requirements of Asia, which is likely to be invariably affected by projected climate change.

**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 (Sukumar et al., 2003; Christensen et al., 2004; Tserendash et al., 2005). The limited herbaceous production, heat stress from higher temperature, and limited water intake due to a decrease in rainfall could cause reduced milk yields in animals and an increased incidence of some diseases.

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**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. For example, India’s surplus grain in past few years has been used to provide food aid to drought-affected Cambodia (Fischer et al., 2002). However, increasing urbanisation and population in Asia will likely 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). Localised increases in food prices could be frequently observed. Subsistence producers growing crops, such as sorghum, millet, 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, is likely to remain very high in several developing countries with an additional 49 million, 132 million and 266 million people of Asia projected under A2 scenario without carbon fertilisation that could be at risk of hunger by 2020, 2050 and 2080, respectively (Parry et al., 2004). In terms of percent increase in risk hunger, it is projected under A2 scenario without CO2fertilisation that an increase of 7 to 14% by 2020s, 14 to 40% by 2050s and 14 to 137% by 2080s are likely (Parry et al., 2004).

Some recent studies (PAGASA, 2001; Sukumar et al., 2003; Batima et al., 2005b) confirm TAR findings that grasslands, livestock and water resources in marginal areas of Central Asia and South-East Asia are likely to be vulnerable to climate change. Food insecurity and loss of livelihood are likely to be 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 likely improve land conditions and reduce pressures arising from climate change.

**10.4.1.5 Pests and diseases**

Some studies (Rosenzweig et al., 2001; FAO, 2004c) agree that higher temperatures and longer growing seasons could result in increased pest populations in temperate regions of Asia. CO2 enrichment and changes in temperature may also affect ecology, the evolution of weed species over time and the competitiveness of C3 v. C4 weed species (Ziska, 2003). Warmer winter temperatures would reduce winter kill, favouring the increase of insect populations. 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 making the crop more vulnerable.

Climate change, as well as changing pest and disease patterns, will likely affect how food production systems perform 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 likely 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 are also likely to be affected negatively by an increase in food prices that may result from declining food production.

**10.4.2 Hydrology and water resources**

**10.4.2.1 Water availability and demand**

The impacts of climate change on water resources in Asia will be positive in some areas and negative in others. Changes in seasonality and amount of water flows from river systems are likely to occur due to climate change. In some parts of Russia, climate change could significantly alter the variability of river runoff such that extremely low runoff events may occur much more frequently in the crop growing regions of the south west (Peterson et al., 2002). Changes in runoff of river basins could have a significant effect on the power output of hydropower generating countries like Tajikistan, which is the third-highest producer in the world (World Bank, 2002). Likewise, surface water availability from major rivers like the Euphrates and Tigris may also be affected by alteration of riverflows. In Lebanon the annual net usable water resources will likely decrease by 15% in response to a general circulation model (GCM) estimated average rise in temperature of 1.2°C under doubled CO2 climate, while the flows in rivers are likely to increase in winter and decrease in spring (Bou-Zeid and El-Fadel, 2002) which could negatively affect existing uses of river waters. In North China, irrigation from surface and groundwater sources will meet only 70% of the water requirement for agricultural production, due to the effects of climate change and increasing demand (Liu et al., 2001; Qin, 2002). The maximum monthly flow of the Mekong is estimated to increase by 35 to 41% in the basin and by 16 to 19% in the delta, with lower value estimated for years 2010 to 38 and higher value for years 2070 to 99, compared with 1961 to 90 levels. In contrast, the minimum monthly flows are estimated to decline by 17 to 24% in the basin and 26 to 29% in the delta (see [Chapter 5](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch5.html), [Box 5.3](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch5s5-2-2.html#box-5-3); Hoanh et al., 2004) suggesting that there could be increased flooding risks during wet season and an increased possibility of water shortage in dry season. Flooding could increase the habitat of brackish water fisheries but could also seriously affect the aquaculture industry and infrastructure, particularly in heavily-populated megadeltas. Decrease in dry season flows may reduce recruitment of some species.

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). Climate change-related melting of glaciers could seriously affect half a billion people in the Himalaya-Hindu-Kush region and a quarter of a billion people in China who depend on glacial melt for their water supplies (Stern, 2007). As glaciers melt, river runoff will initially increase in winter or spring but eventually will decrease as a result of loss of ice resources. Consequences for downstream agriculture, which relies on this water for irrigation, will be likely unfavourable in most countries of South Asia. The thawing volume and speed of snow cover in spring is projected to accelerate in North-West China and Western Mongolia and the thawing time could advance, which will increase some water sources and may lead to floods in spring, but significant shortages in wintertime water availability for livestock are projected by the end of this century (Batima et al., 2004, 2005b).

**10.4.2.2 Water quality**

Over-exploitation of groundwater in many countries of Asia has resulted in a drop in its level, leading to ingress of sea water in coastal areas making the sub-surface 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 increases in sea level as a direct impact of global warming (Han et al., 1999). Rising sea level by 0.4 to 1.0 m can induce salt-water intrusion 1 to 3 km further inland in the Zhujiang estuary (Huang and Xie, 2000). Increasing frequency and intensity of droughts in the catchment area will lead to more serious and frequent salt-water intrusion in the estuary (Xu, 2003; Thanh et al., 2004; Huang et al., 2005) and thus deteriorate surface and groundwater quality.

**10.4.2.3 Implications of droughts and floods**

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 channels by drifting ice, as happened in Central Siberia, Lensk, or enormous precipitation from destructive shower cyclones, as it was in the North Asia Pacific coast, Vladivostok (Izrael et al., 2002a). A projected increase in surface air temperature in North-West China will result in a 27% decline in glacier area (equivalent to the ice volume of 16,184 km3), a 10 to 15% decline in frozen soil area, an increase in flood and debris flow, and more severe water shortages (Qin, 2002). The duration of seasonal snow cover in alpine areas, namely the Tibetan Plateau, Xinjiang and Inner Mongolia of China, will shorten and snow cover will thaw out in advance of the spring season, leading to a decline in volume and resulting in severe spring droughts. Between 20 to 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 socio-economic development on water resources is likely to grow. Higashi et al. (2006) project that future flood risk in Tokyo, Japan between 2050 to 2300 under SRES A1B is likely to be 1.1 to 1.2 times higher than the present condition.

The gross per capita water availability in India will decline from about 1,820 m3/yr in 2001 to as low as about 1,140 m3/yr in 2050 (Gupta and Deshpande, 2004). India will reach a state of water stress before 2025 when the availability falls below 1000 m3 per capita (CWC, 2001). The projected decrease in the winter precipitation over the 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 rainwater 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 South-East Asia in the foreseeable future as the number of people living under severe water stress is likely to increase substantially in absolute terms. It is estimated that under the full range of SRES scenarios, 120 million to 1.2 billion, and 185 to 981 million people will experience increased water stress by the 2020s, and the 2050s, respectively (Arnell, 2004). The decline in annual flow of the Red River by 13 to 19% and that of Mekong River by 16 to 24% by the end of 21st century will contribute in increasing water stress (ADB, 1994).

**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 was 1.8 ± 0.3 mm/yr, and sea-level rise of the order of 2 to 3 mm/yr is considered likely during the early 21st century as a consequence of global warming (Woodroffe et al., 2006). However, the sea-level rise in Asia is geographically variable and an additional half a metre of sea-level rise is projected for the Arctic during this century (ACIA, 2005). The rising rates of sea level vary considerably from 1.5 to 4.4 mm/yr along the East Asia coast, due to regional variation in land surface movement (Mimura and Yokoki, 2004). The projected rise of mean high-water level could be greater than that of mean sea level (Chen, 1991; Zhang and Du, 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 to 60 cm, 50 to 70 cm and 70 to 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 north-western 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, 2005).

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 will tend to worsen the currently eroding coasts (Huang and Xie, 2000). In Boreal Asia, coastal erosion will be enhanced as rising sea level and declining sea ice allow higher wave and storm surge to hit the shore (ACIA, 2005). The coastal recession can add up to 500 to 600 m in 100 years, with a rate of between 4 to 6 m/yr. The coastal recession by thermal abrasion is expected to accelerate by 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, decreasing sediment flux is generally a main cause of coastal erosion. Available evidence suggests a tendency of river sediment to further decline that will tend to worsen coastal erosion in Asia (Liu et al., 2001).

Projected sea-level rise could flood the residence of millions of people living in the low lying areas of South, South-East and East Asia such as in Vietnam, Bangladesh, India and China (Wassmann et al., 2004; Stern, 2007). 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 projected to increase the annual number of people flooded in coastal populations 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 South-East Asia, specifically from Thailand to Vietnam including Indonesia and the Philippines (Wassmann et al., 2004). The potential impacts of one metre sea-level rise include inundation of 5,763 km2 and 2,339 km2 in India and in some big cities of Japan, respectively (TERI, 1996; Mimura and Yokoki, 2004). For one metre sea-level rise with high tide and storm surge, the maximum inundation area is estimated to be 2,643 km2 or about 1.2% of total area of the Korean Peninsula (Matsen and Jakobsen, 2004). In China, a 30 cm sea-level rise would inundate 81,348 km2 of coastal lowland (Du and Zhang, 2000).

The coastal lowlands below the elevation of 1,000-year storm surge are widely distributed in Bangladesh, China, Japan, Vietnam and Thailand, where millions of people live (Nicholls, 2004). In Japan, an area of 861 km2 of coastal lowland is located below high water level mainly in large cities like Tokyo, Osaka and Nagoya. A one metre rise in sea level could put up to 4.1 million people at risk (Mimura and Yokoki, 2004). Using a coarse digital terrain model and global population distribution data, it is estimated that more than 1 million people will be directly affected by sea-level rise in 2050 in each of the Ganges-Brahmaputra-Meghna delta in Bangladesh, the Mekong delta in Vietnam and the Nile delta in Egypt (see [Chapter 6](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6.html), [Box 6.3](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-4-1-2.html#box-6-3); Ericson et al., 2005). Damages in flooded areas are largely dependent on the coastal protection level. It can be much less in highly protected coasts like in Japan but can be very high such as in coastal areas of South Asia where the protection level is low. A 30 cm rise in sea level will increase coastal flooding areas by five or six times in both the ‘with’ and ‘without protection’ scenarios in the Changjiang and Zhujiang deltas. Similarly, the flooding areas in the Huanghe delta for a 100 cm rise in sea level are almost the same under the ‘without protection’ and ‘existing protection’ scenarios. These two cases indicate that the current protection level is insufficient to protect the coasts from high sea-level rise (Du and Zhang, 2000; Li et al., 2004a). Further climate warming may lead to an increase in tropical cyclone destructive potential, and with an increasing coastal population substantial increase in hurricane-related losses in the 21st century is likely (Emanuel, 2005).

In summary, 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.

[AR4 Repo](http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm)

**10.4.3.2 Deltas, estuaries, wetland and other coastal ecosystems**

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 groundwater for irrigation and reservoir construction upstream. In the Tibetan Plateau and adjoining region, sediment starvation is generally the main cause of shrinking of deltas. Annual mean sediment discharge in the Huanghe delta during the 1990s was only 34% of that observed during the 1950s and 1970s. The Changjiang sediment discharge will also be reduced by 50% on average after construction of the Three-Gorges Dam (Li et al., 2004b). Saltwater intrusion in estuaries due to decreasing river runoff can be pushed 10 to 20 km further inland by the rising sea level (Shen et al., 2003; Yin et al., 2003; Thanh et al., 2004).

Many megacities in Asia are located on deltas formed during sea-level change in the Holocene period (Hara et al., 2005). These Asian megacities with large populations and intensified socio-economic 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 km2 of Mekong River delta is projected to be flooded. In addition, 2,500 km2 of mangrove will be completely lost, while approximately 1,000 km2 of cultivated farm land and sea product culturing area will become salt marshes (Tran et al., 2005).

Rise in water temperatures and eutrophication in the Zhujiang and Changjiang estuaries have led to the formation of the bottom oxygen-deficient horizon and an increase in the frequency and intensity of red tides (Hu et al., 2001). Projected increases in the 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 and Neckles, 1999; Simas et al., 2001; Lu, 2003; Paerl et al., 2003).

Recent risk analysis of coral reefs suggests that between 24% and 30% of the reefs in Asia are projected to be lost during the next 2 to 10 years and 10 to 30 years, respectively (14% and 18% for global), unless the stresses are removed and relatively large areas are protected ([Table 10.6](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-4-3-2.html#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 under IS92a emission scenario (IPCC, 1992; Sheppard, 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 sea-surface temperatures (SST) continue to cause major bleaching events (see [Chapter 6](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6.html), [Section 6.2.5](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-2-4.html#6-2-5), [Box 6.1](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-2-1.html#box-6-1)), and reduce the capacity of reefs to calcify due to CO2 increase, most human efforts will be futile (Kleypas et al., 1999; Wilkinson, 2002).