11

Asia

MURARI LAL (INDIA), HIDEO HARASAWA (JAPAN), AND
DANIEL MURDIYARSO (INDONESIA)

Lead Authors:
W.N. Adger (UK), S. Adhikary (Nepal), M. Ando (Japan), Y. Anokhin (Russia), R.V. Cruz (Philippines), M. Ilyas (Malaysia), Z. Kopaliani (Russia), F. Lansigan (Philippines), Congxian Li (China), A. Patwardhan (India), U. Safriel (Israel), H. Suharyono (Indonesia), Xinshi Zhang (China)

Contributing Authors:
M. Badarch (Mongolia), Xiongwen Chen (China), S. Emori (Japan), Jingyun Fang (China), Qiong Gao (China), K. Hall (USA), T. Jarupongsakul (Thailand), R. Khanna-Chopra (India), R. Khosa (India), M.P. Kirpes (USA), A. Lelakin (Russia), N. Mimura (Japan), M.Q. Mirza (Bangladesh), S. Mizina (Kazakhstan), M. Nakagawa (Japan), M. Nakayama (Japan), Jian Ni (China), A. Nishat (Bangladesh), A. Novoplansky (Israel), T. Nozawa (Japan), W.T. Piver (USA), P.S. Ramakrishnan (India), E. Rankova (Russia), T.L. Root (USA), D. Saltz (Israel), K.P. Sharma (Nepal), M.L. Shrestha (Nepal), G. Srinivasan (India), T.S. Teh (Malaysia), Xiaoping Xin (China), M. Yoshino (Japan), A. Zangvil (Israel), Guangsheng Zhou (China)

Review Editors:
Su Jilan (China) and T. Ososkova (Uzbekistan)

CONTENTS

Executive Summary **535**

11.1. The Asian Region **539**
11.1.1. Background 539
11.1.2. Physical and Ecological Features 539
11.1.2.1. Regional Zonation 539
11.1.2.2. Trends and Variability in Key Climate Variables 541
11.1.2.3. Extreme Events and Severe Weather Systems 543
11.1.3. Scenarios of Future Climate Change 544
11.1.3.1. Surface Air Temperature 544
11.1.3.2. Diurnal Temperature Range 547
11.1.3.3. Precipitation 548
11.1.3.4. High-Resolution Climate Change Experiments 550
11.1.4. Sensitivity, Key Vulnerabilities, and Adaptability 551
11.1.4.1. Sensitivity and Key Vulnerabilities 551
11.1.4.2. Adaptability 552

11.2. Key Regional Concerns **552**
11.2.1. Ecosystems and Biodiversity 553
11.2.1.1. Mountain and Highland Systems 553
11.2.1.2. Lakes/Streams, Rivers, and Glaciers 553
11.2.1.3. Forests, Grasslands, and Rangelands 554
11.2.1.4. Drylands 554
11.2.1.5. Cryosphere and Permafrost 555
11.2.1.6. Protected Areas and Risks to Living Species 555
11.2.2. Agriculture and Food Security 556
11.2.2.1. Production Systems 556
11.2.2.2. Grain Supply and Demand in Asia 558
11.2.2.3. Food Security 560
11.2.3. Hydrology and Water Resources 562
11.2.3.1. Water Availability 562
11.2.3.2. Water Needs and Management Implications 565
11.2.4. Oceanic and Coastal Ecosystems 566
11.2.4.1. Oceans and Coastal Zones 566
11.2.4.2. Deltas, Estuarine, and Other Coastal Ecosystems 567
11.2.4.3. Coral Reefs 567
11.2.4.4. Fisheries and Aquaculture 568
11.2.4.5. Tropical Cyclone and Storm Surges 568
11.2.4.6. Potential Impacts and Coastal Zone Management 569
11.2.5. Human Health 570
11.2.5.1. Thermal Stress and Air Pollution-Related Diseases 570
11.2.5.2. Vector-Borne Diseases 570
11.2.5.3. Diseases Resulting from Higher UV-B Exposures 571
11.2.5.4. Other Diseases 571
11.2.6. Human Dimensions 572
11.2.6.1. Climate Extremes and Migration 572
11.2.6.2. Infrastructure Linkages 572
11.2.6.3. Industry, Energy, and Transportation 572
11.2.6.4. Financial Aspects 573

11.3. Vulnerability and Adaptation Potential **574**
11.3.1. Resilience of Resources, Populations, and Infrastructure 574
11.3.2. Regional and Sectoral Strategies 576
11.3.2.1. Boreal Asia 576
11.3.2.2. Arid and Semi-Arid Asia 576
11.3.2.3. Temperate Asia 576
11.3.2.4. Tropical Asia 577
11.3.3. Institutional and Financial Barriers 578

11.4. Synthesis **578**
11.4.1. Key Observations and Uncertainties 578
11.4.2. Future Needs 580

References **581**

EXECUTIVE SUMMARY

Will the Climate in Asia Change?

Continuing emissions of greenhouse gases from human activities are likely to result in significant changes in mean climate and its intraseasonal and interannual variability in the Asian region. Given the current state of climate modeling, projections of future regional climate have only limited confidence. Currently available general circulation models (GCMs) suggest 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. Under the combined influence of greenhouse gas and sulfate aerosols, surface warming would be restricted to about 2.5°C in the 2050s and about 4°C in the 2080s. In general, projected warming over Asia is higher during Northern Hemisphere (NH) winter than during summer for both time periods. The rise in surface air temperature is likely to be most pronounced over boreal Asia in all seasons. GCM simulations project relatively more pronounced increases in minimum temperature than in maximum temperature over Asia on an annual mean basis, as well as during winter, hence a decrease in diurnal temperature range (DTR). During summer, however, an increase in DTR is projected, suggesting that the maximum temperature would have more pronounced increases relative to the minimum temperature. The summertime increase in DTR over central Asia is likely to be significantly higher relative to that in other regions.

In general, all GCMs simulate an enhanced hydrological cycle and an increase in area-averaged annual mean rainfall over Asia. An annual mean increase in precipitation of approximately 7% in the 2050s and approximately 11% in the 2080s over the land regions of Asia is projected from future increases in atmospheric concentration of greenhouse gases. Under the combined influence of greenhouse gases and sulfate aerosols, the projected increase in precipitation is limited to about 3% and 7% in the 2050s and 2080s, respectively. The projected increase in precipitation is greatest during NH winter for both time periods. The increase in annual and winter mean precipitation is projected to be highest in boreal Asia; as a consequence, the annual runoff of major Siberian rivers is expected to increase significantly. Although area-averaged annual mean precipitation is projected to increase in temperate Asia, a decline in summer precipitation is likely over the central parts of arid and semi-arid Asia. Because the rainfall over this region is already low, severe water-stress conditions—leading to expansion of deserts—are quite possible, with rises in surface air temperature and depletion of soil moisture. GCMs show high uncertainty in future projections of winter and summer precipitation over south Asia (with or without aerosol forcings). Because much of tropical Asia is intrinsically linked with the annual monsoon cycle, research into a better understanding of the future behavior of the monsoon and its variability is warranted.

Is Asia Vulnerable to Projected Climate Change?

Climate change-induced vulnerabilities in Asia have to be understood against the backdrop of the physical, economic, and social environment of the countries in the region. They not only provide benchmarks against which vulnerabilities are to be assessed but also the potential for adaptation to them. The socioeconomic environment of many countries in Asia is characterized by high population density and relatively low rates of economic growth. Surface water and groundwater resources in Asian countries play vital roles in forestry, agriculture, fisheries, livestock production, and industrial activity. The water and agriculture sectors are likely to be most sensitive to climate change-induced impacts in Asia. Forest ecosystems in boreal Asia would suffer from floods and increased volume of runoff associated with melting of permafrost regions. The dangerous processes of permafrost degradation resulting from global warming strengthen the vulnerability of all relevant climate-dependent sectors affecting the economy in high-latitude Asia. Although the frequency and severity of floods eventually would increase in many countries of Asia, arid and semi-arid regions of Asia could experience severe water-stress conditions. The stresses of climate change are likely to disrupt the ecology of mountain and highland systems in Asia. Major changes in high-elevation ecosystems of Asia can be expected as a consequence of the impacts of climate change. Many species of mammals and birds and a large population of many other species in Asia could be exterminated as a result of the synergistic effects of climate change and habitat fragmentation. Glacial melt also is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear.

Agricultural productivity in Asia is likely to suffer severe losses because of high temperature, severe drought, flood conditions, and soil degradation; food security of many developing countries in the region would be under tremendous threat. There are likely to be large-scale changes in productivity of warmwater and coolwater fish in many countries in Asia. Sea-level rise would cause large-scale inundation along the vast Asian coastline and recession of flat sandy beaches. The ecological security of mangroves and coral reefs around Asia would be put at risk.

The monsoons in tropical Asia could become more variable if El Niño-Southern Oscillation (ENSO) events become stronger and more frequent in a warmer atmosphere. 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.

Major Risks in Asia from Climate Change

Based on present scientific research, the following risks linked to changes in climate and its variability for Asia are identified:[1]

- The dangerous processes of permafrost degradation resulting from global warming would increase the vulnerability of many climate-dependent sectors affecting the economy in boreal Asia. ***
- Surface runoff increases during spring and summer periods would be pronounced in boreal Asia. ***
- The frequency of forest fires is expected to increase in boreal Asia. ***
- The large deltas and coastal low-lying areas of Asia could be inundated by sea-level rise. ****
- The developing countries of temperate and tropical Asia already are quite vulnerable to extreme climate events such as droughts and floods; climate change and its variability could exacerbate these vulnerabilities. ****
- Increased precipitation intensity, particularly during the summer monsoon, could increase flood-prone areas in temperate and tropical Asia. There is a potential for drier conditions in arid and semi-arid Asia during summer, which could lead to more severe droughts. ***
- Freshwater availability is expected to be highly vulnerable to anticipated climate change. ****
- Tropical cyclones could become more intense. Combined with sea-level rise, this impact would result in enhanced risk of loss of life and properties in coastal low-lying areas of cyclone-prone countries of Asia. ***
- Crop production and aquaculture would be threatened by a combination of thermal and water stresses, sea-level rise, increased flooding, and strong winds associated with intense tropical cyclones. ****
- Warmer and wetter conditions would increase the potential for a higher incidence of heat-related and infectious diseases in tropical and temperate Asia. ***
- Climate change would exacerbate threats to biodiversity resulting from land-use/cover change and population pressure in Asia.***

[1]Uncertainties in observations, mechanisms, and scenarios are identified with a five-point scale, from "very low confidence" (*) to "very high confidence" (*****). The confidence scale has the following probability range: VL = Very Low (<5% probability); L = Low (5–33%); M = Medium (33–67%); H = High (67–95%); and VH = Very High (>95%).

Adaptation to Climate Change in Asia

The impacts of climate change are likely to be felt most severely in the majority of developing countries of Asia because of resource and infrastructure constraints (e.g., disparities in income level, technological gaps). These countries must develop and implement incremental adaptation strategies and policies to exploit "no regret" measures and "win-win" options. Detailed and reliable regional scenarios of climate change must be developed and used in rigorous vulnerability analysis (e.g., low-probability/high-consequence events vs. high-probability/ high-consequence events, risk perceptions). To understand which adaptation opportunities will be most cost-effective and have the greatest value, emphasis must be given to characteristics of system vulnerability such as resilience, critical thresholds, and coping ranges, which are highly dependent on regions and nations.

It is important to consider climate change in planning, designing, and implementing development activities in climate-sensitive resources for Asia, particularly where:

- Climate change may cause irreversible or catastrophic impacts
- Decisions with a long lifetime, such as building of infrastructure, are being made
- Development trends such as development of low-lying coastal areas increase vulnerability to climate change.

Two general strategies on adaptation can be used. The first is a macro strategy that involves rapid development. Sustainable and equitable development will increase income levels, education, and technical skills and improve public food distribution, disaster preparedness and management, and health care systems in developing countries of Asia. All of these changes could substantially enhance social capital and reduce the vulnerability of these countries to climate change.

The second strategy is a micro strategy that involves modifying the management of sectors that are most sensitive to climate change. This approach entails developing new institutions or modifying existing institutions related to these sectors that promote rather than discourage adaptation to climate change. It also involves modifying climate-sensitive infrastructures that are already planned or implemented or other long-term decisions that are sensitive to climate to incorporate the risks of climate change.

Based on the foregoing principles, specific adaptation strategies for countries in the Asian region have been identified in the relevant sectors (e.g., water resources, agriculture and food security, coastal resources, human health, and ecosystems and biodiversity). These strategies are summarized in Box 11-1.

Each subregion has its priority adaptation sector for its own situation. Food security, disaster preparedness and management, soil conservation, and human health sectors also appear to be crucial for countries with large populations (e.g., China, India,

Box 11-1. Summary of Potential Sector-Wide Adaptation Options for Subregions of Asia

Agriculture
- *Boreal Asia*: Adopt suitable crops and cultivars; make optimum use of fertilizers and adaptation of agro-technologies.
- *Arid and Semi-Arid Asia*: Shift from conventional crops to intensive greenhouse agriculture/aquaculture; protect against soil degradation.
- *Temperate Asia*: Adopt heat-resistant crops, water-efficient cultivars with resistance to pests and diseases, soil conservation.
- *Tropical Asia*: Adjust cropping calendar and crop rotation; develop and promote use of high-yielding varieties and sustainable technological applications.

Water Resources
- *Boreal Asia*: Develop flood-protection systems in north Asia (required because of permafrost melting and increased streamflow volume/surface runoff); enhance management of international rivers.
- *Arid and Semi-Arid Asia*: Enhance conservation of freshwater supply as option for extreme water-stress conditions.
- *Temperate Asia*: Flood and drought control measures required; improve flood warning and forecasting systems, including disaster management.
- *Tropical Asia*: Develop flood- and drought-control management systems; reduce future developments in floodplains; use appropriate measures for protection against soil erosion; conserve groundwater supply, water impoundments, and efficient water resource systems.

Ecosystems and Biodiversity
- Assess risks to endemic species and ecosystems.
- Introduce integrated ecosystem planning and management.
- Reduce habitat fragmentation and promote development of migration corridors and buffer zones.
- Encourage mixed-use strategies.
- Prevent deforestation and conserve natural habitats in climatic transition zones inhabited by genetic biodiversity of potential for ecosystem restoration.

Coastal Resources
- *Boreal Asia*: Modify infrastructures to accommodate sea-level rise.
- *Arid and Semi-Arid Asia*: Protect lakes and water reservoirs; develop aquaculture farming techniques.
- *Temperate Asia*: Follow setback examples for new coastal development; evaluate coastal subsidence rates in sensitive coastal regions; prepare contingency plans for migration in response to sea-level rise; improve emergency preparedness for weather extremes (e.g., typhoons and storm surges).
- *Tropical Asia*: Protect wetlands and allow for migration; prepare contingency plans for migration in response to sea-level rise; improve emergency preparedness for weather extremes (e.g., cyclones and storm surges); evaluate coastal subsidence rates in sensitive coastal regions.
- *Common Adaptation*: Implement coastal zone management; protect marine resources.

Human Health
- Build heat-resistant urban infrastructures and take additional measures to reduce air and water pollution.
- Adapt technological/engineering solutions to prevent vector-borne diseases/epidemics.
- Improve health care system, including surveillance, monitoring, and information dissemination.
- Improve public education and literacy rate in various communities.
- Increase infrastructure for waste disposal.
- Improve sanitation facilities in developing countries.

Cross-Cutting Issues
- Continue monitoring and analysis of variability and trends in key climatic elements.
- Improve weather forecasting systems in the region.
- Improve and implement reforms on land-use planning.
- Apply new techniques for confident projection of regional climate change and its variability, including extreme events.
- Improve coordination of climate change adaptation activities among countries in the region.
- Keep the nongovernmental organization (NGO) community and the public aware of developments on risks of climate change and involve them in planning, adaptation, and mitigation strategies.
- Take advantage of traditional knowledge in planning for the future.

Bangladesh). Adaptations proposed for human health, which essentially involve improving the health care system, are changes that are needed anyway to address the current human health situation in many Asian countries. Adaptations to deal with sea-level rise, potentially more intense cyclones, and threats to ecosystems and biodiversity should be considered high priority in temperate and tropical Asian countries.

The design of an optimal adaptation program in any country would have to be based on comparison of damages avoided with costs of adaptation. Other factors also should enter the decisionmaking process, such as the impacts of policies on society in terms of employment generation and opportunities, improved air and water quality, and the impacts of policies on broader concerns for equitable and sustainable development.

11.1. The Asian Region

11.1.1. Background

Following publication of its Second Assessment Report (SAR) and on recommendation of the Subsidiary Body for Scientific and Technological Advice of the Conference of the Parties, the Intergovernmental Panel on Climate Change (IPCC) published its *Special Report on the Regional Impacts of Climate Change* in early 1998, providing assessments of the vulnerability of natural ecosystems, socioeconomic sectors, and human health to climate change for 10 regions of the globe (IPCC, 1998). That Special Report served as guidance material, illustrating for the first time the potential character and magnitude of region-specific impacts—though often in qualitative sense only, based on a diverse range of methods and tools.

Akey message of the regional assessments in that report was that "many systems and policies are not well adjusted even to today's climate and climate variability." Several examples cited, based on information gathered during country study and other projects, demonstrate current vulnerability in the Asian region as a result of increasing risks to human life and property from floods, storms, and droughts in recent decades. The report suggests that, as a consequence of climate change, there could be a large reduction in the area and productivity of forests in boreal Asia. In arid and semi-arid regions of Asia, water shortage—already a limiting factor for ecosystems, food and fiber production, human settlements, and human health—may be exacerbated by climate change. Limited water supplies and land degradation problems are likely to threaten the food security of some countries in this region. Major changes in the composition and distribution of vegetation types of semi-arid areas—for example, grasslands, rangelands, and woodlands—are anticipated. In temperate Asia, changes in temperature and precipitation may result in altered growing seasons and boundary shifts between grasslands, forests, and shrublands. An increase in temperature could lead to oxygen depletion in aquatic ecosystems, fish diseases, and introduction of unwanted species, as well as potential negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships in temperate Asia. Arise in sea level will endanger sandy beaches in the coastal zones and add further to the problems of tectonically and anthropogenically induced land subsidence in deltaic regions of temperate Asia. Substantial elevational shifts of ecosystems in the mountains and uplands of tropical Asia are projected. Increases in temperature and seasonal variability in precipitation are expected to result in more rapid recession of Himalayan glaciers. Climate change impacts could result in significant changes in crop yields, production, storage, and distribution in this region. Densely settled and intensively used low-lying coastal plains, islands, and deltas in Asia are extremely vulnerable to coastal erosion and land loss, inundation and sea flooding, and upstream movement of saline water fronts as a result of sea-level rise. The incidence and extent of vector-borne diseases, which are significant causes of mortality and morbidity in tropical Asia, are likely to spread into new regions on the margins of present endemic areas as a result of climate change.

The 1998 Special Report underscores that, in many countries of Asia, economic policies and conditions (e.g., taxes, subsidies, and regulations) that shape decisionmaking, development strategies, and resource-use patterns (hence environmental conditions) hinder implementation of adaptation measures. For example, water is subsidized in most developing countries of Asia, encouraging overuse (which draws down existing sources) and discouraging conservation measures that may be elements of future adaptation strategies. Other examples are inappropriate land-use zoning and subsidized disaster insurance, which encourage infrastructure development in areas that are prone to flooding or other natural disasters—areas that could become even more vulnerable as a result of climate change. Adaptation and better incorporation of the long-term environmental consequences of resource use can be brought about through a range of approaches, including strengthening legal and institutional frameworks, removing pre-existing market distortions (e.g., subsidies), correcting market failures (e.g., failure to reflect environmental damage or resource depletion in prices or inadequate economic valuation of biodiversity), and promoting public participation and education. These types of actions would adjust resource-use patterns to current environmental conditions and better prepare systems for potential future changes.

The 1998 Special Report emphasizes that the challenge lies in identifying opportunities that would facilitate sustainable development by making use of existing technologies and developing policies that make climate-sensitive sectors resilient to today's climate variability. This strategy will require developing countries of Asia to have access to appropriate technologies, information, and adequate financing. In addition, adaptation will require anticipation and planning; failure to prepare systems for projected change in climate means, variability, and extremes could lead to capital-intensive development of infrastructure or technologies that are ill-suited to future conditions, as well as missed opportunities to lower the costs of adaptation.

Subsequent to publication of the 1998 Special Report, 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 (GHGs) and aerosols that alter the radiative forcings of climate have been made. Details on future projections of climatic and environmental changes on finer scales also are now better understood. This chapter presents an update on the climate change projections for Asia and examines how projected changes in climate could affect social, environmental, and economic sectors in the region.

11.1.2. Physical and Ecological Features

11.1.2.1. Regional Zonation

The Asian continent is bounded on the north by the Arctic Ocean, on the east by the Pacific Ocean, and on the south by the Indian Ocean; the western boundary, with Europe, runs roughly north-south along the eastern Ural Mountains, the

Zhem River, the Caspian Sea, the Kuma-Manych Depression, the Black Sea, the Aegean Sea, the Mediterranean Sea, the Suez Canal, and the Red Sea. The world's largest plateau—the Tibetan Plateau, with an average elevation of more than 4,000 m—is located in Asia. Mt. Everest, the highest peak in the world (8,848 m), lies near the southern border of this plateau. The islands of Sri Lanka and Taiwan (China) and the archipelagoes of Indonesia, the Philippines, and Japan also are part of Asia. Asia is the most populous of the continents. Its total population in 1998 is estimated to be about 3,589 million, of which almost 65% is rural. The coastline of Asia is 252,770 km long.

Based on broad climatic and geographical features, the Asian region can be divided into four subregions: boreal Asia, arid and semi-arid Asia, temperate Asia, and tropical Asia (Figure 11-1). This chapter discusses key climatological, ecological, and socioeconomic features of each of these subregions and the countries falling within them, as well as various aspects of vulnerability, impacts, and adaptation in relation to climate change for each of these regions.

Boreal Asia is located on the northern margins of the Eurasian continent between 50°N and the Arctic Circle. Boreal forests cover most of this region. Siberia, which is a part of Russia (the main country in the region), has a mean monthly temperature of about -50°C in January and is the coldest region of the northern hemisphere in winter. Three Siberian rivers—the Ob, the Yenissey, and the Lena—contribute about 42% of total runoff from all rivers of the Arctic basin (CAFW, 1998). In the heart of this region is one of the world's largest and oldest lakes, Baikal, the age of which is estimated to be about 25–30 million years (Kuzmin *et al*., 1997). Lake Baikal contains as much as 85% of Russian surface freshwaters (Izrael *et al.*, 1997a; Anokhin and Izrael, 2000). There is evidence of recession of permafrost in recent decades (ICRF, 1998).

Arid and semi-arid Asia extends from 22°N to 50°N and from 30°E to 105°E; it includes more than 20 countries of the Middle East and central Asia. Many of the countries in the region are landlocked. Many storms develop locally (*in situ*) over central Asia; some move into the region from the west. The maximum frequency of cyclones occurs in January and March. Despite this cyclonic activity, very little precipitation is recorded over most of the region because of the lack of moisture. Most of the region has a precipitation-to-potential evapotranspiration ratio of less than 0.45, which is typical of a semi-arid and arid

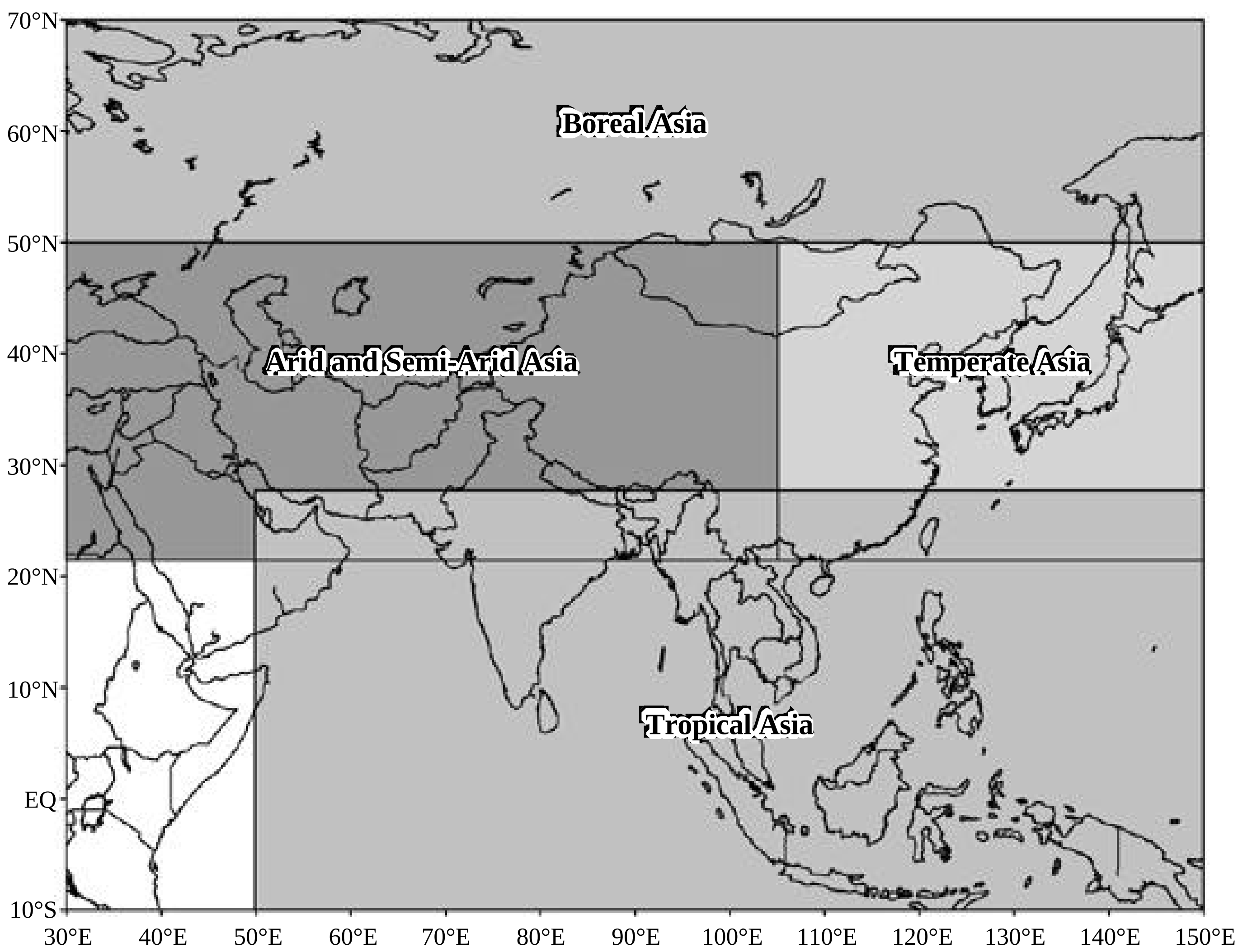

Figure 11-1: Geographical domain of Asia and its subregions.

climate. Grasslands, rangelands, and deserts dominate most of arid and semi-arid Asia.

Temperate Asia extends from 22°N to 50°N and from 105°E to 150°E; it includes eastern China, the Japanese islands, the Korean peninsula, Mongolia, and Taiwan (China). Geographically, the region is located on the eastern part of the Eurasian continent—the world's largest continent—and borders the Pacific, the world's largest ocean. The east-west distance of the area is about 5,000 km; its north-south extent is about 3,000 km. Much of the natural forest in the region has long been destroyed. Broad plains have been cultivated and irrigated, and natural grasslands have been used for animal husbandry for centuries.

Tropical Asia extends from 10°S to 28°N and from 50°E to 150°E; it includes several countries of south Asia, which are influenced predominantly by the monsoons. The region 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 seven of the 25 largest cities in the world. Agriculture is the main industry in several countries of this region. Exploitation of natural resources associated with rapid urbanization, industrialization, and economic development has led to increasing air and water pollution, land degradation, and other environmental problems in countries of this region. Climate change represents a further stress. Over the long period of human occupation in the region, human use systems have developed some resilience to a range of environmental stresses (IPCC, 1998).

Table 11-1 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 some of the countries of Asia.

11.1.2.2. Trends and Variability in Key Climate Variables

11.1.2.2.1. Surface air temperature

Climate differs widely within Asia. In boreal Asia, the climate generally is humid and cool; it is classified as continental type. Permafrost covers as much as 90% of boreal Asia. An average annual mean increase in surface air temperature of about 2.9°C in the past 100 years has been observed in boreal Asia. Warming was more pronounced during the period 1951–1995 in all of boreal Asia region except for the coast of the Arctic Ocean and Chukotka (Rankova, 1998). The mean surface air temperature increase is most pronounced in the winter, at a rate of approximately 4.4°C over the past 100 years (Gruza *et al*., 1997). Summer temperatures in central Siberia have exhibited decreasing trends, however.

The climate of arid and semi-arid Asia is the warm temperate type, with hot and wet or dry summers. The highest value of DTR (on the order of 20°C) is experienced in this region. A mean maximum temperature of >45°C in July is not uncommon in some parts of arid Asia. In most of the Middle East, the long time series of surface air temperature shows a warming trend. An increasing tendency in spatially averaged seasonal and annual air temperatures has been observed in Kazakhstan over the past century. Maximal warming has occurred in spring. The mean annual surface temperature has risen by about 1.3°C during 1894–1997 (Pilifosova *et al.*, 1997); in the arid regions of China, air temperature has obviously increased since the 1970s (Chen, 1995). In Pakistan, annual mean surface temperature has a consistent rising trend since the beginning of 20th century (Chaudhari, 1994).

In temperate Asia, the average annual mean surface temperature in Mongolia has increased by approximately 0.7°C over the past 50 years; consequently, noticeable changes have taken place in the length of the cold and warm seasons (Khuldorj et al., 1998). Surface temperature in northeast China has increased in winter but decreased in summer since 1905 (Ren and Zhou, 1994; Ren, 1998); observations also reveal a 1–2°C decrease in temperature in some parts of southeastern China. In Japan, the surface air temperature has shown a warming trend during the past century (Yoshino, 1998a; Japan Meteorological Agency, 1999).

Tropical Asia has a unique climatological distinction because of the pervasive influence of the monsoon. In tropical Asia, climate uniformity is differentiated by three factors: latitude, relief, and continentality. The entire tropical Asia region stretches over 38° in latitude, so the differences resulting from this factor are pronounced. In spite of some differences, the climates of countries have one factor in common: The Asian monsoon modulates them all to a large extent. For countries near the Equator, only small seasonal variations occur, although most countries in this region experience clearly marked cold and warm seasons. The spatial range of temperature in this region is significantly large during winter. Extreme temperatures of over 45°C occur over the northwest part of the region during May-June. Several countries in this region have reported increasing surface temperature trends in recent decades. In Vietnam, annual mean surface temperature has increased over the period 1895–1996, with mean warming estimated at 0.32°C over the past 3 decades. Annual mean surface air temperature anomalies over Sri Lanka during the period 1869–1993 suggest a conspicuous and gradually increasing trend of about 0.30°C per 100 years (Rupakumar and Patil, 1996). The warming trend over India has been reported to be about 0.57°C per 100 years (Rupakumar *et al*., 1994).

11.1.2.2.2. Precipitation

Rainfall in boreal Asia is highly variable on seasonal and interannual as well as spatial scales. The time series of annual mean precipitation in Russia suggests a decreasing trend; these tendencies have amplified during 1951–1995, especially in warm years (Rankova, 1998). In long-term mean precipitation, a decreasing trend of about -4.1 mm/month/100 years has been reported in boreal Asia. During the past 10–15 years, however,

***Table 11-1**: Key information on the socioeconomics of some of Asian countries (WRI, 1998; FAO, 1999a).*

Country/Region	Population, 1998 (1000s)	Gross Domestic Product, 1995 (per capita US$)	Land Area (10^3 ha)	Crop Land, 1992–1994 (10^3 ha)	Total Forest Cover, 1995 (10^3 ha)	Annual Internal RWR, 1998[a] (per capita m^3)	Cereal Food Prod., Avg. 1994–1996[a] (10^3 t)	Annual Sea Food, Avg. 1993–1995[a] (per capita kg)
Boreal Asia								
– Russia	147231	2333	1688850	133072	763500	29115	69524	15.4
Arid and Semi-Arid Asia								
– Afghanistan	23364	x	65209	8054	1398	2354	3019	x
– Armenia	3646	783	2820	582	334	2493	256	1.2
– Azerbaijan	7714	461	8660	1967	990	1069	981	4.8
– Georgia	5428	427	6970	1036	2988	10682	543	6.8
– Iran	73057	1756	162200	18500	1544	1755	16944	5.1
– Iraq	21795	2755	43737	5550	83	1615	2312	1.2
– Israel	5883	16645	2067	434	102	289	153	20.3
– Jordan	5956	1187	8893	405	45	114	93	3.4
– Kazakhstan	16854	1273	267073	35239	10504	4484	12340	3.5
– Kuwait	1809	15760	1782	5	5	11	2	10.4
– Kyrgyzstan	4497	685	19180	1387	730	10394	1132	0.1
– Lebanon	3194	3703	1023	306	52	1315	76	0.7
– Oman	2504	5483	21246	63	0	393	5	x
– Pakistan	147811	445	77088	21323	1748	1678	23818	2.4
– Saudi Arabia	20207	6875	214969	3777	222	119	3871	6.7
– Syrian Arab Republic	15335	1182	18378	5985	219	456	5816	0.6
– Tajikistan	6161	343	14060	846	410	11171	288	0.6
– Turkmenistan	4316	961	46993	1471	3754	232	988	8.4
– Turkey	63763	2709	76963	27611	8856	3074	28179	7.9
– United Arab Emirates	2354	17696	8360	75	60	64	7	21.5
– Uzbekistan	24105	947	41424	4618	9119	704	2718	1.0
Temperate Asia								
– China	1255091	572	929100	95145	133323	2231	416954	14.5
– Japan	125920	40846	37652	4467	25146	4344	14566	67.6
– Korea, DPR	23206	x	12041	2007	6170	2887	5022	46.3
– Korea, Republic	46115	10142	9873	2053	7626	1434	6877	51.2
– Mongolia	2624	349	156650	1357	9406	9375	264	0.9
Tropical Asia								
– Bangladesh	124043	246	13017	8849	1010	10940	27887	8.7
– Bhutan	1917	172	4700	136	2756	49557	111	x
– Cambodia	10754	276	17652	3832	9830	8195	3024	8.5
– India	975772	349	297319	169569	65005	1896	213326	4.0
– Indonesia	206522	1003	181157	31146	109791	12251	57197	15.7
– Laos	5358	361	23080	900	12435	50392	1485	6.6
– Malaysia	21450	4236	32855	7536	15471	21259	2158	28.3
– Myanmar	47625	x	65755	10067	27151	22719	20040	16.1
– Nepal	23168	197	14300	2556	4822	7338	5686	x
– Philippines	72164	1093	29817	9320	6766	4476	15119	33.5
– Singapore	3491	25156	61	1	4	172	x	x
– Sri Lanka	18450	720	6463	1889	1796	2341	2313	15.7
– Thailand	61400	2868	51311	21212	11630	1845	25759	26.3
– Vietnam	77896	279	32549	6738	9117	4827	26040	13.1

[a] Column 6 = annual internal renewable water resources (per capita, m^3), 1998; column 7 = cereal food production (thousands of metric tons), average 1994–96; and column 8 = per capita annual food supply from fish and seafood (kg), average 1993–95.

precipitation has increased, mostly during the summer-autumn period (Izrael *et al*., 1997b). As a result of this increase in precipitation, water storage in a 1-m soil layer has grown by 10–30 mm (Robock *et al*., 2000). The large upward trends in soil moisture (of more than 1 cm/10 years) have created favorable conditions for infiltration into groundwater. The levels of major aquifers have risen by 50–100 cm; the growth of groundwater storage has resulted in increasing ground river recharge and considerable low-water runoff.

Annual mean rainfall is considerably low in most parts of the arid and semi-arid region of Asia. Moreover, temporal variability is quite high: Occasionally, as much as 90% of the annual total is recorded in just 2 months of the year at a few places in the region. Rainfall observations during the past 50 years in some countries in the northern parts of this region have shown an increasing trend on annual mean basis. A decreasing trend in annual precipitation for the period 1894–1997 has been observed in Kazakhstan. The precipitation in spring, summer, and autumn, however, has shown slight increasing trends. In Pakistan, seven of 10 stations have shown a tendency toward increasing rainfall during monsoon season (Chaudhari, 1994).

In temperate Asia, the East Asian monsoon greatly influences temporal and spatial variations in rainfall. Annual mean rainfall in Mongolia is 100–400 mm and is confined mainly to summer. Summer rainfall seems to have declined over the period 1970–1990 in Gobi; the number of days with relatively heavy rainfall events has dropped significantly (Rankova, 1998). In China, annual precipitation has been decreasing continuously since 1965; this decrease has become serious since the 1980s (Chen *et al*., 1992). The summer monsoon is reported to be stronger in northern China during globally warmer years (Ren *et al.,* 2000). On the other hand, drier conditions have prevailed over most of the monsoon-affected area during globally colder years (Yu and Neil, 1991).

In tropical Asia, hills and mountain ranges cause striking spatial variations in rainfall. Approximately 70% of the total annual rainfall over the Indian subcontinent is confined to the southwest monsoon season (June-September). The western Himalayas get more snowfall than the eastern Himalayas during winter. There is more rainfall in the eastern Himalayas and Nepal than in the western Himalayas during the monsoon season (Kripalani *et al*., 1996). The annual mean rainfall in Sri Lanka is practically trendless; positive trends in February and negative trends in June have been reported, however (Chandrapala and Fernando, 1995). In India, long-term time series of summer monsoon rainfall have no discernible trends, but decadal departures are found above and below the long time averages alternatively for 3 consecutive decades (Kothyari and Singh, 1996). Recent decades have exhibited an increase in extreme rainfall events over northwest India during the summer monsoon (Singh and Sontakke, 2001). Moreover, the number of rainy days during the monsoon along east coastal stations has declined in the past decade. A long-term decreasing trend in rainfall in Thailand is reported (OEPP, 1996). In Bangladesh, decadal departures were below long-term averages until 1960; thereafter they have been much above normal (Mirza and Dixit, 1997).

11.1.2.3. Extreme Events and Severe Weather Systems

Apart from intraseasonal and interannual variability in climate, extreme weather events such as heat waves associated with extreme temperatures, extratropical and tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, snow avalanches, thunderstorms, and dust storms are known to cause adverse effects in widely separated areas of Asia. There is some evidence of increases in the intensity or frequency of some of these extreme weather events on regional scales throughout the 20th century, although data analyses are relatively poor and not comprehensive (Balling and Idso, 1990; Bouchard, 1990; Agee, 1991; Yu and Neil, 1991; Chen *et al*., 1992; Ostby, 1993; Bardin, 1994; Born, 1996). For example, increases in climate extremes in the western Siberia-Baikal region and eastern parts of boreal Asia have been reported in recent decades (Gruza and Rankova, 1997; Gruza *et al*., 1999). There also are reports of an increase in thunderstorms over the land regions of tropical Asia (Karl *et al*., 1995). The frequency and severity of wildfires in grasslands and rangelands in arid and semi-arid Asia have increased in recent decades (Pilifosova *et al*., 1996).

Some mountains in Asia have permanent glaciers that have vacated large areas during the past few decades, resulting in increases in glacial runoff. As a consequence, an increased frequency of events such as mudflows and avalanches affecting human settlements has occurred (Rai, 1999). 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 some places. For example, low- and mid-lying parts of central Asia are likely to change gradually into more arid, interior deserts.

Countries in temperate Asia have been frequented by many droughts in the 20th century. In China, droughts in 1972, 1978, and 1997 have been recorded as the most serious and extensive. A large number of severe floods also have occurred in China, predominately over the middle and lower basins of the Yangtze (Changjiang), Huanghe, Huaihe, and Haihe Rivers (Ji *et al*., 1993). Severe flooding with daily rainfall exceeding 25 cm struck during July and August 1998 in Korea. In Japan, drought disasters are significantly more frequent during years following ENSO warm events than in normal years.

Floods, droughts, and cyclones are the key natural disasters in tropical Asia. The average annual flood covers vast areas throughout the region: In Bangladesh, floods cover 3.1 Mha; the total flood-prone area in India is about 40 Mha (Mirza and Ericksen, 1996). In India, chronically drought-affected areas cover the western parts of Rajasthan and the Kutch region of Gujarat. However, drought conditions also have been reported in Bihar and Orissa States in India. In Bangladesh, about 2.7

Mha are vulnerable to drought annually; there is about 10% probability that 41–50% of the country is experiencing drought in a given year (Mirza, 1998). Drought or near-drought conditions also occur in parts of Nepal, Papua New Guinea, and Indonesia, especially during El Niño years. In India, Laos, the Philippines, and Vietnam, drought disasters are more frequent during years following ENSO events. At least half of the severe failures of the Indian summer monsoon since 1871 have occurred during El Niño years (Webster *et al*. 1998). In the event of enhanced anomalous warming of the eastern equatorial Pacific Ocean, such as that observed during the 1998 El Niño, a higher frequency of intense extreme events all across Asia is possible.

11.1.3. Scenarios of Future Climate Change

Increases in atmospheric concentrations of GHGs from anthropogenic activities would warm the earth-atmosphere system. The radiative forcing inferred from likely future increases in GHGs and sulfate aerosols as prescribed under IS92a emission scenarios (Leggett *et al.*, 1992; IPCC, 1995) has been used in recent numerical experiments performed with coupled atmosphere-ocean global climate models (AOGCMs). Projections of future regional climate change and also most of the impact assessment studies for Asia cited herein are based on these numerical experiments (see Chapter 3 for further details).

To develop climate change scenarios on regional scales, it is first necessary to examine if the coupled AOGCMs are able to simulate the dynamics of present-day regional climate. The multi-century control integrations of AOGCMs unforced by anthropogenic changes in atmospheric composition offer an excellent opportunity to examine the skill of individual models in simulating the present-day climate and its variability on regional scales (Giorgi and Francisco, 2000; Lal *et al*., 2000). A model validation exercise carried out for Asia and its subregions has indicated that each of these models shows large seasonal variations in surface air temperature over boreal Asia and only small seasonal variations over southeast tropical Asia (Figure 11-2). However, many of the AOGCMs have only limited ability for realistic portrayal of even large-scale precipitation distribution over Asia. Seasonal variations in observed precipitation over the South Asia region as a consequence of summer monsoon activity are poorly simulated by most of the models (Figure 11-3). Moreover, none of the seven models can reproduce the observed precipitation climatology over the Tibetan Plateau (Figure 11-4). Based on the pattern correlation coefficients and root mean square errors between the observed and model-simulated seasonal mean sea-level pressure, surface air temperature, and rainfall patterns over land regions of Asia and other relevant considerations in this validation exercise, the HadCM2, ECHAM4, CSIRO, and CCSR/NIES AOGCMs (developed at U.K. Hadley Climate Centre, German Climate Research Centre, Australian Commonwealth Scientific and Industrial Research Organisation, and Japanese Center for Climate System Research/National Institute for Environmental Studies, respectively) are rated to have some skill in simulating the broad features of present-day climate and its variability over Asia (Lal and Harasawa, 2000).

11.1.3.1. Surface Air Temperature

Climate change scenarios that are based on an ensemble of results as inferred from skilled AOGCMs for Asia and its subregions on annual and seasonal mean basis are presented in Table 11-2. Three future time periods centered around the 2020s (2010–2029), the 2050s (2040–2069), and the 2080s (2070–2099) have been considered here for developing scenarios of changes in surface air temperature and precipitation relative to the baseline period of 1961–1990. The projected area-averaged annual mean warming is 1.6±0.2°C in the 2020s, 3.1±0.3°C in the 2050s, and 4.6±0.4°C in the 2080s over land regions of

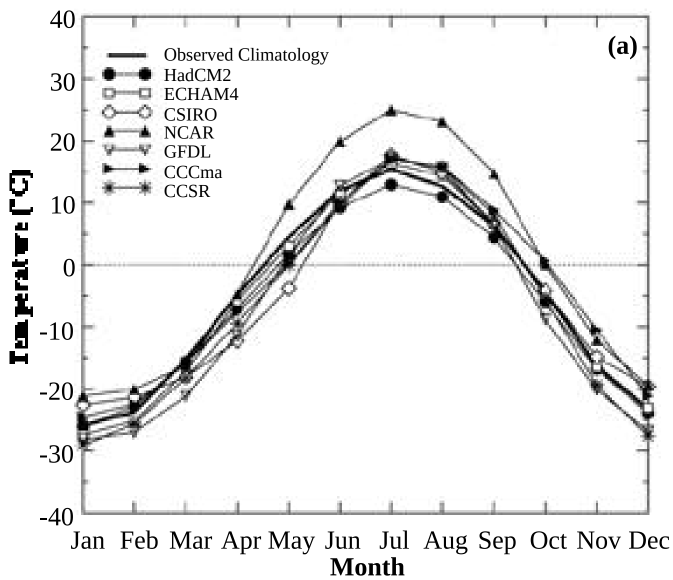

Figure 11-2: Validation of simulated and observed area-averaged annual cycles of surface air temperature over boreal (a) and southeast Asia (b) regions.

Asia as a result of increases in the atmospheric concentration of GHGs. Under the combined influence of GHGs and sulfate aerosols, surface warming will be restricted to 1.4±0.3°C in the 2020s, 2.5±0.4°C in the 2050s, and 3.8±0.5°C in the 2080s. In general, projected warming over Asia is higher during NH winter than during summer for all time periods (see also Giorgi and Francisco, 2000). The area-averaged increase in surface air temperature is likely to be most pronounced over boreal Asia and least in southeast Asia in all seasons (Lal and Harasawa, 2001). It is evident from Table 11-2 that even though aerosol forcing reduces surface warming, the magnitude of projected warming is still considerable and could substantially impact the Asian region.

In December 1998, the writing team for the IPCC *Special Report on Emission Scenarios* (SRES) released a preliminary set of four SRES "marker" scenarios: A1, A2, B1, and B2 (Nakicenovic *et al.*, 1998). Scenario B1 projects the most conservative future emissions of GHGs from Asia; scenario A2 is characteristic of scenarios with higher rates of GHG emissions in combination with higher sulfate and other aerosol emissions. The A1 scenario family has since been further divided into three groups that describe alternative directions of technological change in the energy system (IPCC, 2000). The three A1 groups are distinguished by their technological emphasis: fossil fuel-intensive (A1FI), nonfossil energy sources (A1T), or a balance across all sources (A1B). Projections of future aerosol loading as envisaged in SRES marker scenarios are significantly lower compared to the IS92a scenario.

Figure 11-5 illustrates the trends in area-averaged annual mean surface air temperature increase over land regions of Asia as

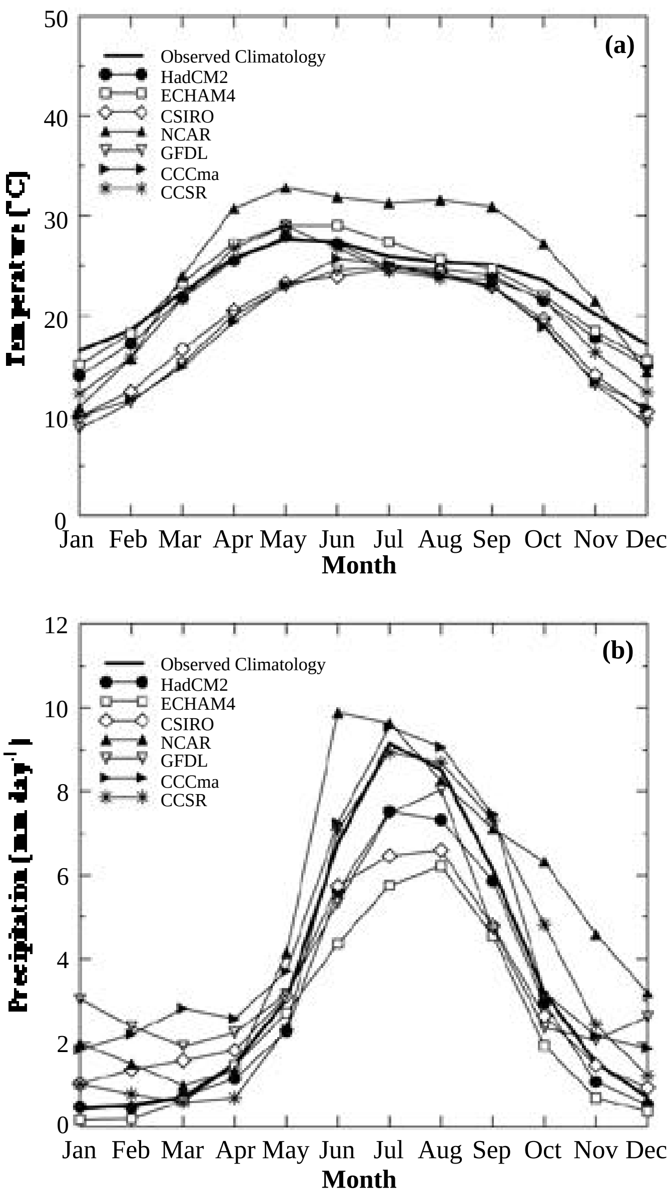

Figure 11-3: Validation of simulated and observed area-averaged annual cycles of surface air temperature (a) and precipitation (b) over south Asia.

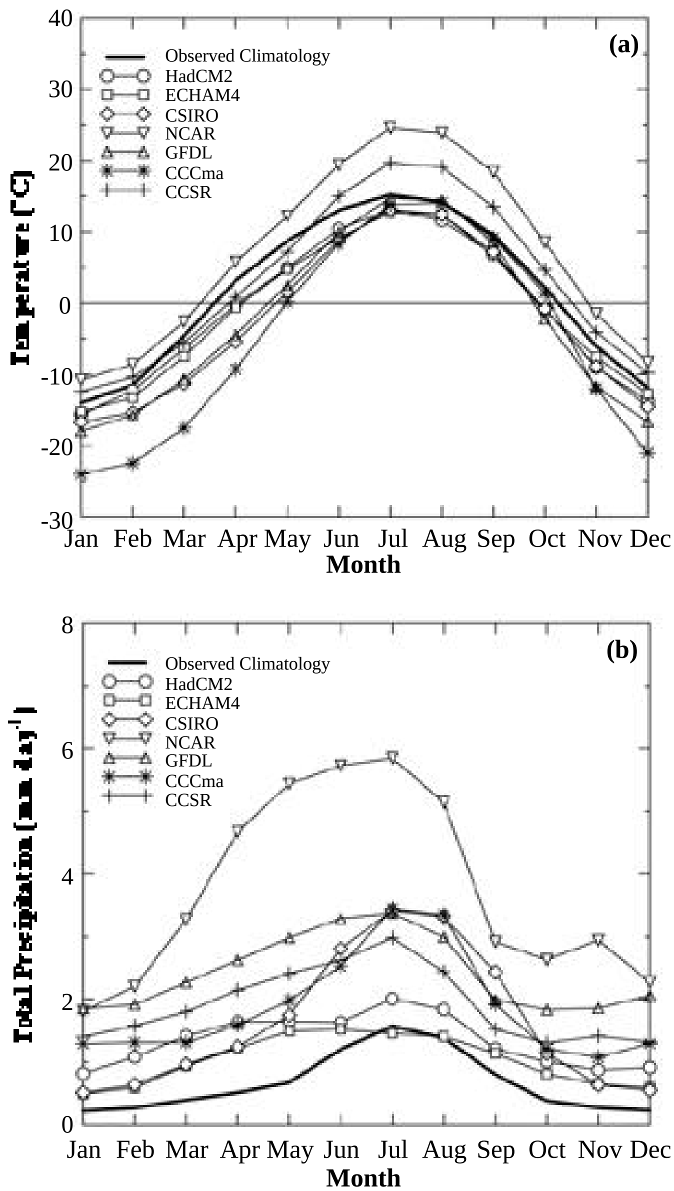

Figure 11-4: Validation of simulated and observed area-averaged annual cycles of surface air temperature (a) and precipitation (b) over Tibetan Plateau.

***Table 11-2**: Plausible changes in area-averaged surface air temperature (top) and precipitation (bottom) over Asia and its subregions as a result of future increases in greenhouse gases (under IS92a emission scenarios), as inferred from an ensemble of data generated in experiments with CCSR/NIES, CSIRO, ECHAM4, and HadCM2 AOGCMs. Numbers in parentheses are area-averaged changes when direct effects of sulfate aerosols are included.*

	Temperature Change (°C)								
	2020s			**2050s**			**2080s**		
Regions	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	1.58	1.71	1.45	3.14	3.43	2.87	4.61	5.07	4.23
	(1.36)	(1.52)	(1.23)	(2.49)	(2.77)	(2.23)	(3.78)	(4.05)	(3.49)
Boreal	2.17	2.66	1.71	4.32	5.52	3.29	6.24	8.04	4.82
	(1.88)	(2.21)	(1.47)	(3.52)	(4.46)	(2.83)	(5.30)	(6.83)	(4.24)
Arid/Semi-Arid									
– Central Asia	1.61	1.56	1.77	3.18	2.81	3.55	4.83	4.41	5.34
	(1.47)	(1.55)	(1.49)	(2.69)	(2.61)	(2.59)	(4.15)	(3.78)	(4.36)
– Tibet	1.77	1.90	1.62	3.38	3.55	3.19	5.04	5.39	4.69
	(1.56)	(1.83)	(1.40)	(2.62)	(2.94)	(2.27)	(4.06)	(4.32)	(3.73)
Temperate	1.49	1.74	1.23	2.86	3.26	2.48	4.34	5.11	3.67
	(1.19)	(1.50)	(0.99)	(2.10)	(2.40)	(1.72)	(3.31)	(3.83)	(2.77)
Tropical									
– South Asia	1.36	1.62	1.13	2.69	3.25	2.19	3.84	4.52	3.20
	(1.06)	(1.19)	(0.97)	(1.92)	(2.08)	(1.81)	(2.98)	(3.25)	(2.67)
– SE Asia	1.05	1.12	1.01	2.15	2.28	2.01	3.03	3.23	2.82
	(0.96)	(0.94)	(0.96)	(1.72)	(1.73)	(1.61)	(2.49)	(2.51)	(2.34)

	Precipitation Change (%)								
	2020s			**2050s**			**2080s**		
Regions	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	3.6	5.6	2.4	7.1	10.9	4.1	11.3	18.0	5.5
	(2.3)	(4.3)	(1.8)	(2.9)	(6.5)	(1.5)	(7.0)	(12.1)	(3.5)
Boreal	6.1	11.1	2.6	12.8	23.8	5.1	20.7	39.5	7.7
	(6.7)	(10.7)	(3.3)	(12.0)	(19.7)	(7.1)	(18.9)	(31.5)	(10.3)
Arid/Semi-Arid									
– Central Asia	1.3	3.0	-2.1	1.3	6.9	-2.3	-1.3	6.9	-4.0
	(1.1)	(2.7)	(5.9)	(0.6)	(1.4)	(0.7)	(-3.6)	(1.0)	(-1.8)
– Tibet	5.9	8.9	4.4	9.0	19.2	4.7	12.8	25.6	5.7
	(3.4)	(7.4)	(1.7)	(7.5)	(14.8)	(1.7)	(11.5)	(18.8)	(3.8)
Temperate	3.9	4.2	3.7	7.9	13.3	5.4	10.9	20.1	7.8
	(0.9)	(0.4)	(1.2)	(1.3)	(4.3)	(0.7)	(4.8)	(7.1)	(3.1)
Tropical									
– South Asia	2.9	2.7	2.5	6.8	-2.1	6.6	11.0	5.3	7.9
	(1.0)	(-10.1)	(2.8)	(-2.4)	(-14.8)	(0.1)	(-0.1)	(-11.2)	(2.5)
– SE Asia	2.4	1.4	2.1	4.6	3.5	3.4	8.5	7.3	6.1
	(1.7)	(3.3)	(1.2)	(1.0)	(2.9)	(2.6)	(5.1)	(5.9)	(4.9)

simulated with CCSR/NIES AOGCMs for the IS92a scenario (GHG only and GHG + aerosols) and for the new SRES "marker" emission scenarios. Projections of future sulfate aerosol loading in SRES scenarios are significantly lower. Because the treatment of aerosol and GHG radiative effects in the old and new sets of scenario experiments is different, quantitative comparison of the results should be made with care. Nonetheless, the generally higher projected surface warming trend for SRES scenarios in the latter half of the 21st century is partially a result of intensive reduction of aerosol emissions. Projected surface warming trends for the IS92a and B1 emission pathways are close to each other. Maximum warming is simulated for the A1 emission scenario during the first half of the 21st century but is carried forward to the A2 emission scenario in the latter half of the 21st century. Projections of regional climate change that use these newer sets of emission scenarios for GHGs have not yet been thoroughly assessed for their applications in impact assessment studies.

11.1.3.2. Diurnal Temperature Range

One important aspect of the observed temperature change over the globe during the past century relates to its asymmetry during the day and night (Karl *et al.*, 1991). Observed warming in surface air temperatures over several regions of the globe has been reported to be associated with an increase in minimum temperatures (accompanied by increasing cloudiness) and a decrease in DTR (Hansen *et al.*, 1998).

AOGCM simulations with increasing concentrations of GHGs in the atmosphere suggest relatively more pronounced increases in minimum temperature than in maximum temperature over Asia on an annual mean basis, as well as during the winter, for the 2050s and the 2080s—hence a decrease in DTR (Table 11-3). During the summer, however, an increase in DTR is simulated—suggesting thereby that the maximum temperature would have a more pronounced increase relative to the minimum temperature (Lal and Harasawa, 2001). The summertime increase in DTR over central Asia is significantly higher relative to that in other regions. Most of the subregions follow the same pattern of change in DTR, except south and southeast Asia. A marginal increase in DTR during the winter and on an annual mean basis is simulated over southeast Asia. Over the south Asia region, a decrease in DTR on an annual mean basis and during the winter and a more pronounced decrease in DTR during the summer are projected. The significantly higher decrease in DTR over

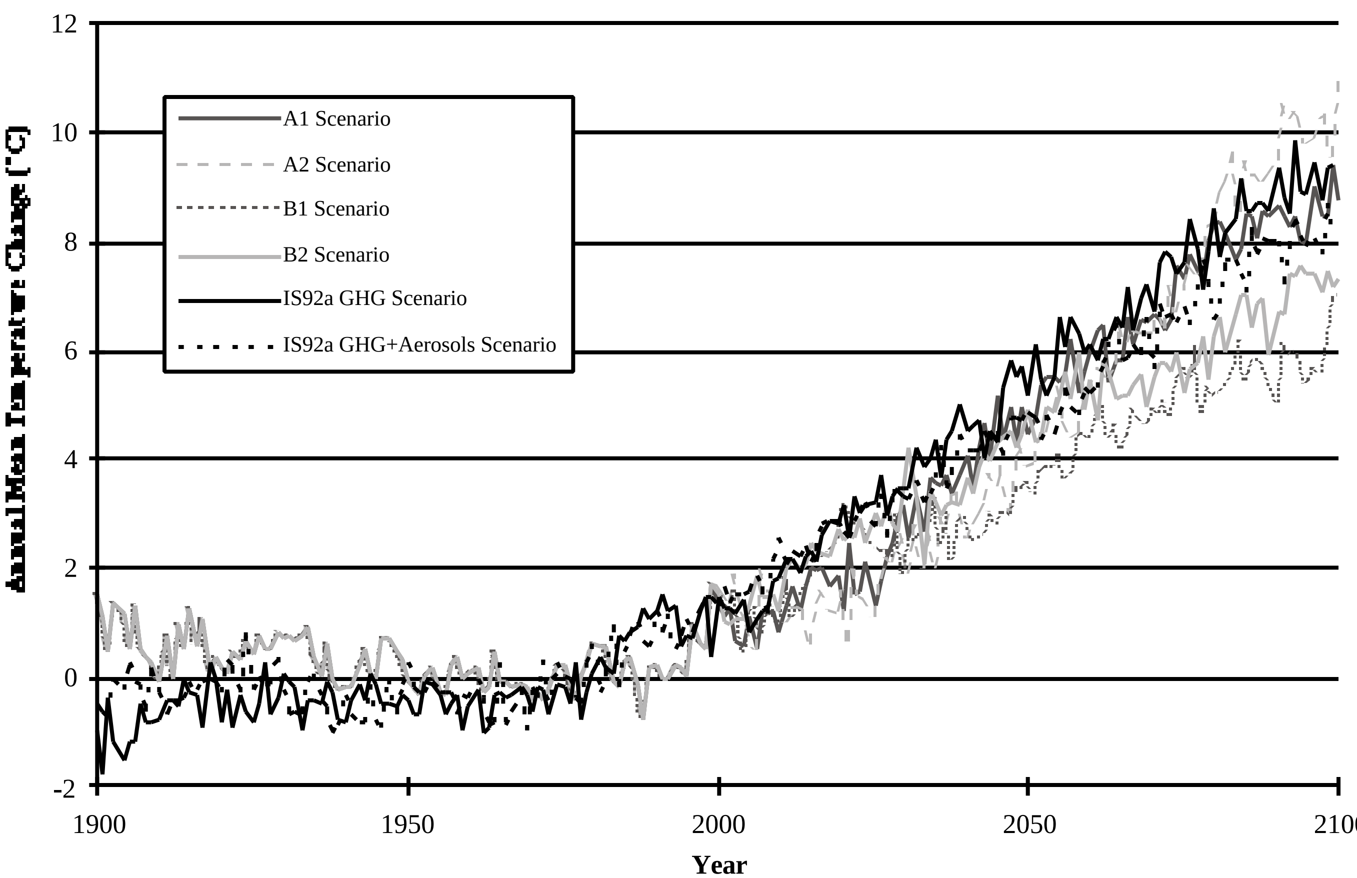

Figure 11-5: Future trends in area-averaged annual mean temperature increase over land regions of Asia as simulated by CCSR/NIES AOGCM for IS92a and SRES emission scenarios. Because the climate sensitivity of model versions used for the new (SRES) and old (IS92a) sets of simulations are different, temperature trends shown are scaled so they can be compared directly; trends for IS92a scenarios are scaled by a factor of 1.56, which is the ratio of climate sensitivity averaged over Asia of new model version to that of old version. Also note that only the direct effect of sulfate aerosols is considered in the IS92a GHG+Aerosols simulation, whereas the direct and indirect effects of sulfate and carbon aerosols are considered in SRES simulations.

***Table 11-3**: Projected changes in diurnal temperature range over Asia and its subregions under IS92a emission scenarios, as inferred from an ensemble of data generated in experiments with CCSR/NIES, CSIRO, ECHAM4, and HadCM2 AOGCMs.*

	Greenhouse Gases						***Greenhouse Gases + Sulfate Aerosols***					
	2050s			**2080s**			**2050s**			**2080s**		
Regions	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer	Annual	Winter	Summer
Asia	-0.15	-0.26	1.42	-0.27	-0.45	1.36	-0.17	-0.13	-0.54	-0.27	-0.26	-0.54
Boreal	-0.38	-0.52	1.67	-0.53	-0.81	1.62	-0.45	-0.34	-0.49	-0.57	-0.53	-0.48
Arid/ Semi-Arid												
– Central	0.13	-0.07	4.64	0.17	-0.11	4.75	-0.02	-0.14	2.20	0.09	-0.04	2.36
– Tibet	-0.34	-0.60	2.01	-0.46	-0.81	1.91	-0.53	-0.63	0.18	-0.67	-0.80	0.13
Temperate	-0.18	-0.31	0.47	-0.23	-0.43	0.44	-0.19	-0.21	-0.83	-0.28	-0.30	-1.05
Tropical												
– South	-0.27	-0.27	-3.06	-0.45	-0.46	-2.89	-0.22	-0.14	-4.97	-0.31	-0.31	-4.95
– Southeast	0.15	0.24	-0.50	0.00	0.09	-0.66	0.35	0.42	-0.98	0.18	0.24	-1.09

south Asia during the summer is a result of the presence of monsoon clouds over the region (Lal *et al.*, 1996). In general, the decline in DTR is slightly moderated in the presence of sulfate aerosols (Lal and Harasawa, 2001). Changes in DTR over Asia in this case suggest a decrease in both seasons. Similar changes also are seen over boreal Asia and temperate Asia.

11.1.3.3. Precipitation

In general, all AOGCMs simulate an enhanced hydrological cycle and an increase in annual mean rainfall over most of Asia (Giorgi and Francisco, 2000). An area-averaged annual mean increase in precipitation of 3±1% in the 2020s, 7±2% in the 2050s, and 11±3% in the 2080s over the land regions of Asia is projected as a result of future increases in the atmospheric concentration of GHGs. Under the combined influence of GHGs and sulfate aerosols, the projected increase in precipitation is limited to 2±1% in the decade 2020s, 3±1% in the 2050s, and 7±3% in the 2080s. Figure 11-6 depicts projected changes in precipitation relative to changes in surface air temperature, averaged for land regions of Asia for each of the four skilled AOGCMs on an annual mean basis as well as during winter and summer for the 2050s and 2080s. The increase in precipitation is maximum during NH winter for both the time periods (Lal and Harasawa, 2000b). Clearly, intermodel differences in projections of precipitation are relatively large particularly during the winter even when they are averaged for the entire Asian continent—suggesting low confidence in projections of future precipitation in current AOGCMs.

The increase in annual mean precipitation is projected to be highest in boreal Asia. During the winter, boreal Asia and the Tibetan Plateau have the most pronounced increase in precipitation (Table 11-2). Over central Asia, an increase in winter precipitation and a decrease in summer precipitation are projected. Because the rainfall over this region is already low, severe water stress conditions—leading to expansion of deserts—are quite possible with a rise in surface air temperature here. The area-averaged annual mean and winter precipitation is projected to increase in temperate Asia. The models show high uncertainty in projections of future winter and summer precipitation over south Asia (with or without direct aerosol forcings). The effect of sulfate aerosols on Indian summer monsoon precipitation is to dampen the strength of the monsoon compared to that seen with GHGs only (Lal *et al.*, 1995a; Mitchell *et al.*, 1995; Cubasch *et al.*, 1996; Roeckner *et al.*, 1999). The overall effect of the combined forcing is at least partly dependent on the land/sea distribution of aerosol forcing and on whether the indirect effect is included along with the direct effect. To date, the effect of aerosol forcing (direct and indirect) on the variability of the monsoon has not been investigated.

Recent observations suggest that there is no appreciable long-term variation in the total number of tropical cyclones observed in the north Indian, southwest Indian, and southwest Pacific Oceans east of 160°E (Neumann, 1993; Lander and Guard, 1998). For the northwest subtropical Pacific basin, Chan and Shi (1996) found that the frequency of typhoons and the total number of tropical storms and typhoons has been more variable since about 1980. Several studies since the SAR have considered likely changes in tropical cyclones (Henderson-Sellers *et al.*, 1998; Knutson et al., 1998; Krishnamurti *et al.*, 1998; Royer *et al.*, 1998). Some of these studies suggest an increase in tropical storm intensities with carbon dioxide (CO_2)-induced warming.

Some of the most pronounced year-to-year variability in climate features in many parts of Asia has been linked to ENSO. Since the SAR, analysis of several new AOGCM results indicates that as global temperatures increase, the Pacific climate will

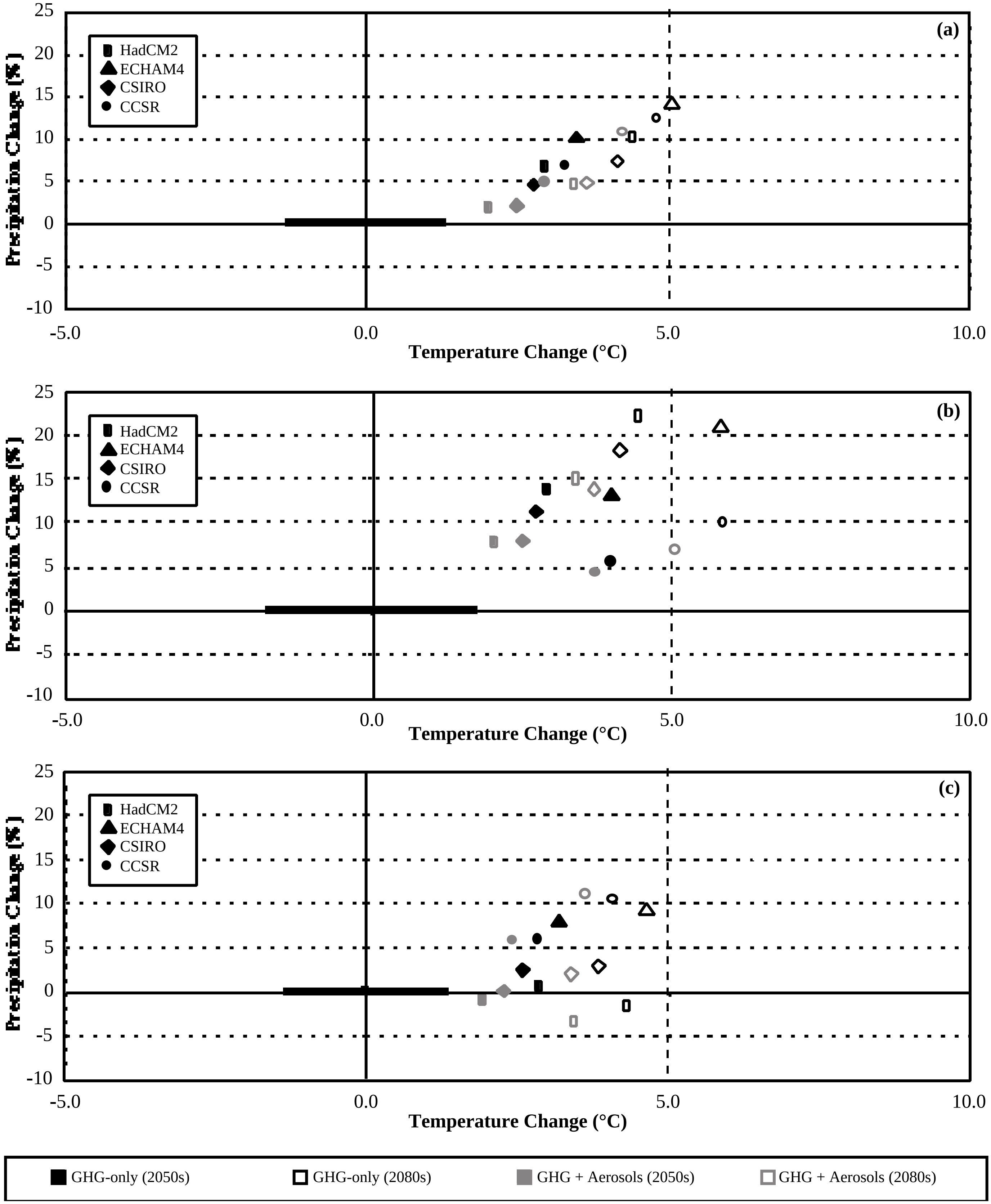

Figure 11-6: Projected changes in area-averaged annual (a) and seasonal [(b) DJF and (c) JJA)] mean surface air temperature and precipitation over land regions of Asia for the 2050s and 2080s as obtained in select AOGCMs.

tend to resemble a more El Niño-like state (Mitchell *et al*., 1995; Meehl and Washington, 1996; Knutson and Manabe, 1998; Boer *et al*., 1999; Timmermann *et al*., 1999). Collins (1999) finds an increased frequency of ENSO events and a shift in their seasonal cycle in a warmer atmosphere: The maximum occurs between August and October rather than around January as currently observed. Meehl and Washington (1996) indicate that future seasonal precipitation extremes associated with a given ENSO event are likely to be more intense in the tropical Indian Ocean region; anomalously wet areas could become wetter, and anomalously dry areas could become drier during future ENSO events.

Several recent studies (Kitoh *et al.*, 1997; Lal *et al.*, 2000) have confirmed earlier results (Kattenberg *et al.*, 1996) indicating an increase in interannual variability of daily precipitation in the Asian summer monsoon with increased GHGs. Lal *et al.* (2000) also report an increase in intraseasonal precipitation variability and suggest that intraseasonal and interannual increases are associated with increased intraseasonal convective activity during the summer. The intensity of extreme rainfall events is projected to be higher in a warmer atmosphere, suggesting a decrease in return period for extreme precipitation events and the possibility of more frequent flash floods in parts of India, Nepal, and Bangladesh (Lal *et al*., 2000). However, Lal *et al*. (1995b) found no significant change in the number and intensity of monsoon depressions (which are largely responsible for the observed interannual variability of rainfall in the central plains of India) in the Bay of Bengal in a warmer climate. Because much of tropical Asia is intrinsically linked with the annual monsoon cycle, a better understanding of the future behavior of the monsoon and its variability is warranted for economic planning, disaster mitigation, and development of adaptation strategies to cope with climate variability and climate change.

11.1.3.4. High-Resolution Climate Change Experiments

Although these AOGCMs treat the complex interactions of atmospheric physics and planetary-scale dynamics fairly well, coarse horizontal resolution in the models restricts realistic simulation of climatic details on spatial variability. For example, tropical precipitation has high temporal and spatial variability, which cannot be resolved realistically in currently available AOGCMs. Many investigations on the ability of GCMs to simulate the Asian monsoon have been reported in the literature (e.g., Meehl and Washington, 1993; Chakraborty and Lal, 1994; Bhaskaran *et al.*, 1995; Lal *et al.*, 1995a, 1997, 1998a,b). These studies suggest that although most GCMs are able to simulate the large-scale monsoon circulation well, generally they are less successful with the summer monsoon rainfall. Since the SAR, nested modeling approaches have been followed to generate high-resolution regional climate scenarios (Jones *et al*., 1995; Lal *et al*., 1998c; Hassell and Jones, 1999) with more realistic mesoscale details and the response of GHG forcings to the surface climatology over the Asian monsoon region.

Large-scale patterns of temperature change simulated by GCMs and nested regional climate models (RCMs) are found to be generally similar under $2xCO_2$ forcing, but the regional model results present some additional details associated with coastline and local topographical features (Hirakuchi and Giorgi, 1995). In addition, projected warming over eastern China region in the summer is less pronounced in the RCM

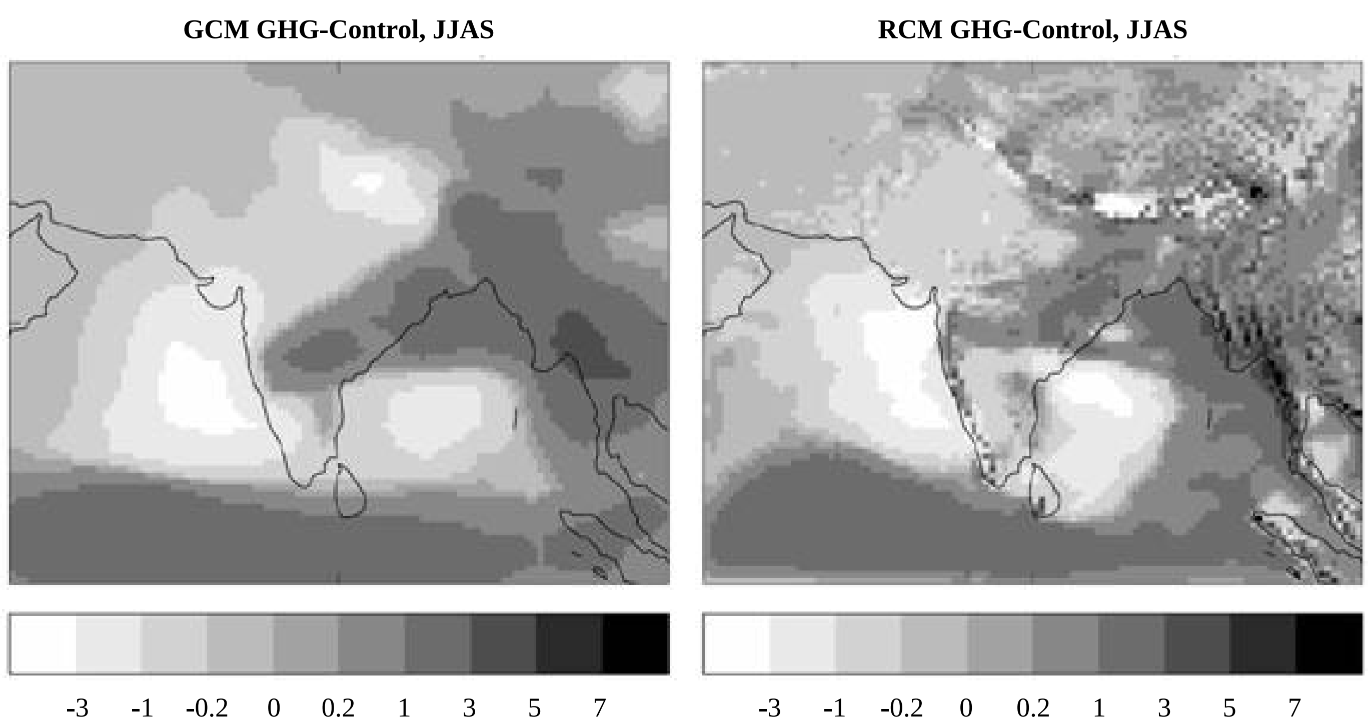

Figure 11-7: Spatial distribution of changes in monsoon rainfall over Indian subcontinent as simulated by Hadley Centre's global and regional climate models at the time of doubling of CO_2 in the atmosphere.

than in the GCM and is characterized by a different spatial pattern. This is related to an increase in monsoon precipitation simulated by the RCM there and associated surface cooling induced by evaporation and cloudiness. Nonetheless, the GCM and RCM simulations suggest a general increase in warming toward higher latitudes and greater warming in winter than in summer. The RCM produces a more pronounced increase in winter precipitation over southeastern China than does the GCM in response to orographic lifting of stronger low-level southerly onshore winds. The RCM also simulates increased precipitation in the monsoon rain belt over east China, Korea, and Japan during the summer.

The increase in surface air temperature simulated by the RCM over central and northern India is not as intense as in the GCM and does not extend as far south (Lal *et al*., 1998c; Hassell and Jones, 1999). These anomalies are linked with changes in surface hydrological variables. Summer precipitation exhibits a more complex pattern of increases and decreases. Whereas an increase in rainfall is simulated over the eastern region of India, northwestern deserts see a small decrease in the absolute amount of rainfall in RCM simulation (Figure 11-7). Changes in soil moisture broadly follow those in precipitation except in eastern India, where they decrease as a result of enhanced drainage from the soil. The largest reductions (precipitation reduced to <1 mm day^{-1}; 60% decline in soil moisture) are simulated in the arid regions of northwest India and Pakistan. The projected increase in precipitation in flood-prone Bangladesh is approximately 20%. Nested RCM simulations have the potential to simulate the onset of the summer monsoon and its active/break cycle over India. The RCM captures the observed precipitation maximum over the southern tip of India during weak monsoon conditions, whereas the GCM does not.

Given the current state of climate modeling, projections of future regional climate have only limited confidence. The degree of confidence that could be attributed to RCM responses in terms of temporal and spatial changes resulting from GHG forcings would depend on more accurate simulation of the space and time evolution of large-scale monsoon circulation features in AOGCMs, as well as additional long-term RCM simulations with better skill. Current efforts on climate variability and climate change studies increasingly rely on 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. Because the anthropogenic aerosol burden in the troposphere would have large spatial and temporal variations in the atmosphere, its future impact on regional scale would be in striking contrast to the impact from GHGs. It has also been suggested that aerosols produced by tropical biomass burning could lead to additional negative radiative forcing (Portmann *et al*., 1997). Considerable uncertainty prevails about the indirect effect of aerosols on tropospheric clouds, which could strongly modulate the climate. The implications of localized radiative forcing on deep convection in tropical Asia and on Hadley circulation are still not understood (Lal *et al*., 2000).

11.1.4. Sensitivity, Key Vulnerabilities, and Adaptability

11.1.4.1. Sensitivity and Key Vulnerabilities

An examination and analysis of the climate change-induced vulnerabilities in Asia has to be undertaken against the backdrop of the physical, economic, and social environment of the countries in the region. They provide not only the benchmark against which vulnerabilities are to be assessed but also the potential for adaptation to them. Surface water and groundwater resources in Asian countries play vital roles in forestry, agriculture, fisheries, livestock production, and industrial activity. The water and agriculture sectors are likely to be most sensitive to climate change-induced impacts in Asia.

As reported in IPCC (1998), climate change in boreal Asia could have serious effects on climate-dependent sectors such as agriculture, forestry, and water resources. Climate change and human activities, for example, may influence the levels of the Caspian and Aral Seas, with implications for the vulnerability of natural and social systems (Kelly *et al*., 1983; Golubtsov *et al.*, 1996; Popov and Rice, 1997). The increase in surface temperature will have favorable effects on agriculture in the northernmost regions of Asia, and a general northward shift of crop zones is expected. However, as much as a 30% decrease in cereal production from the main agriculture regions of boreal Asia by 2050 has been projected (Budyko and Menzhulin, 1996; ICRF, 1998). A decrease in agriculture productivity of about 20% also is suggested in southwestern Siberia (ICRF, 1998). Forest ecosystems in boreal Asia could suffer from floods and increased volume of runoff, as well as melting of permafrost regions. Model-based assessments suggest that significant northward shifts (up to 400 km) in natural forest zones are likely in the next 50 years (Lelyakin *et al*., 1997; Serebryanny and Khropov, 1997). There also is growing anxiety that significant increases in ultraviolet radiation, as observed in recent years, could have serious implications for ecosystems along the Arctic shore of Siberia (Makarov, 1999; Voskoboynikov, 1999; ACIA, 2000).

In arid and semi-arid Asia, the climate limits the portion of land that presently is available for agriculture and livestock production. Croplands in many of the countries in the region are irrigated because rainfall is low and highly variable. The agriculture sector here is potentially highly vulnerable to climate change because of degradation of the limited arable land. Almost two-thirds of domestic livestock are supported on rangelands, although in some countries a significant share of animal fodder also comes from crop residues (IPCC, 1998). The combination of elevated temperature and decreased precipitation in arid and semi-arid rangelands could cause a manifold increase in potential evapotranspiration, leading to severe water-stress conditions. Many desert organisms are near their limits of temperature tolerance. Because of the current marginality of soil-water and nutrient reserves, some ecosystems in semi-arid regions may be among the first to show the effects of climate change. Climate change has the potential to exacerbate the loss of biodiversity in this region.

The major impacts of global warming in temperate Asia will be large northward shifts of subtropical crop areas. Large increases in surface runoff—leading to soil erosion and degradation, frequent waterlogging in the south, and spring droughts in the north—ultimately will affect agriculture productivity (Arnell, 1999). As reported in IPCC (1998), the volume of runoff from glaciers in central Asia may increase three-fold by 2050. Permafrost in northeast China is expected to disappear if temperatures increase by 2°C or more. The northern part of China would be most vulnerable to hydrological impacts of climate change; future population growth and economic development here may exacerbate seriously the existing water shortage. Deltaic coasts in China would face severe problems from sea-level rise. Sea-level rise also will expand the flood-prone area and exacerbate beach erosion in Japan.

In monsoon Asia, the issue of sensitivity of physical and natural systems to the hydrological cycle is linked to major stresses caused by projected climate change on agricultural production and increased exposure of social and economic systems to impacts of extreme events, including forest die-back and increased fire risk; typhoons and tropical storms; floods and landslide; and human disease impacts. These stresses on physical systems translate into key social vulnerabilities, particularly in combination with unsustainable utilization of resources. For example, the drawing down of groundwater resources has increased the rate of relative sea-level change for many of the major cities of coastal Asia, such as Bangkok and Shanghai—thereby increasing the risk from climate change-induced sea-level rise (Jarupongsakul, 1999). Conversion of natural forests to palm oil plantations in many southeast Asian countries during recent decades (particularly Indonesia and Malaysia) increased the probability of uncontrolled forest fires and increased health and biodiversity impacts during the 1997 ENSO event (Yim, 1999; Barber and Schweithelm, 2000). The ecological security of mangroves and coral reefs may be put at risk by climate change. Sea-level rise could cause large-scale inundation along the coastline and recession of flat sandy beaches of south and southeast Asia. Monsoons in tropical Asia could become more variable if ENSO events become stronger and more frequent in a warmer atmosphere (Webster and Yang, 1992; Webster *et al*. 1998).

Vulnerability relates to social or natural systems and is delineated as such. The issues of social and physical vulnerability to climate change are directly related because the major sensitivities of ecological and natural systems across the regions of Asia translate into risks to socioeconomic systems. Social vulnerability is defined as the degree to which individuals or groups are susceptible to impacts; the determinants of social vulnerability are exposure to stress as a result of the impacts of climate change and the underlying social position (Adger, 1999a). On this basis, the key social vulnerabilities in the Asian context occur:

- Where resource-dependent communities have their resilience undermined by increased exposure to the physical stresses in water availability, agricultural impact, and other sensitivities mentioned above
- Where sustainability and equity (Munasinghe, 2000) are sacrificed for economic growth, exposing larger parts of the population to impacts.

11.1.4.2. Adaptability

Climate variability and change, both natural and anthropogenic, cause a wide range of direct and indirect impacts on natural and human systems. To understand which adaptation opportunities will be most cost-effective and have the greatest value, emphasis must be given to characteristics of system vulnerability, such as resilience, critical thresholds, and coping ranges, which are highly dependent on regions and nations. In this respect, lessons learned from past experiences regarding climate variability and change provide essential understanding of processes, actions, and successes.

The impacts of climate change and other drivers of environmental degradation (e.g., disparities in income level, technological gaps) are likely to be felt more severely in developing countries than in developed countries of Asia, irrespective of the magnitude of climate change, because of the poor resource and infrastructure bases. The developing countries need to scope the development of adaptation strategies incrementally to support development of existing policies that exploit "no regret" measures and "win-win" options (Smit *et al*., 2000). Detailed and reliable regional scenarios of climate change need to be developed and used in rigorous vulnerability analysis (e.g., low-probability/high-consequence events versus high-probability/high-consequence events, risk perceptions). In developing countries, adaptation responses are closely linked to developmental activities. Consequently, there are likely to be large spillover effects between adaptation policies and developmental activities. Care in this regard must be taken in the evaluation of adaptation costs and benefits. In developing countries of Asia, options such as population growth control, poverty alleviation, and capacity building in food production, health care delivery, and water resource management hold great potential in creating more resilient social systems that are capable of withstanding the negative impacts of climate change.

11.2. Key Regional Concerns

Despite global technological and economic development, a large proportion of the nearly 1.5 billion people living in severe poverty at the dawn of the new millennium are located in Asia. Global per capita water supplies are declining and are now 30% lower than they were 25 years ago. By 2050, as much as 42% of the world's population may have to live in countries with insufficient freshwater stocks to meet the combined needs of agriculture, industry, and domestic use. The world's population will reach at least 8.9 billion by the middle of the 21st century (United Nations, 1998). India and China alone now account for 38% of the world's population. Most of the additional population would be in developing countries. These countries are likely to suffer adverse agricultural responses; significant changes in seasonal runoff; possibly severe vector-borne diseases; increased risks of severe tropical weather disturbances, including storms; vulnerability to sea-level rise; and other stresses. This section presents key regional concerns of various subregions of Asia related to climate change.

11.2.1. Ecosystems and Biodiversity

11.2.1.1. Mountain and Highland Systems

Relatively hospitable mountain regions in Asia are under pressure from human settlements and commercial cultivation, which have led to land degradation and adverse effects on water supply. Ongoing changes in different mountain systems within Asia include those associated with high crop production and those characterized by extensive animal husbandry and pastureland. Human encroachment in mountain regions has reduced vegetation cover, which has increased soil moisture evaporation, erosion, and siltation—with adverse effects on water quality and other resources. Changes in the snowfall pattern have been observed in mountain and highland systems, particularly in the Himalayas (Verghese and Iyer, 1993). These changes will have wider implications—from marked impact on the monsoon regime to seasonal runoff and vegetation cover, including agriculture. Changes in the hydrological regime also will trigger episodes of extreme events.

One-tenth of the world's known species of higher altitude plants and animals occur in the Himalayas. In addition, some countries in Asia are centers of origin for many crop and fruit-tree species; as such, they are important sources of genes for their wild relatives. Biodiversity is being lost in these regions because of human activities, especially land degradation and the overuse of resources. In 1995, approximately 10% of known species in the Himalayas were listed as threatened, and the number of species on the verge of extinction has increased since then. As a consequence of global warming, the present distribution of species in high-elevation ecosystems is projected to shift to higher elevations, 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 of the Himalayan mountain range. Weedy species with a wide ecological tolerance will have an advantage over others (Kitayama and Mueller-Dombois, 1995). High-elevation tree species—such as *Abies, Acer, and Betula*—prevail in cold climates because of their adaptations to chilling winters. In Japan, the area of suitable habitat at higher elevations has shrunk over the past 30 years, and the variety of alpine plants that grow there has been rapidly reduced (Masuzawa, 1997, 2000). Increases in temperature would result in competition between such species and new arrivals. The sensitivity of alpine flora to climatic factors and, in particular, water stress in the summit region of Mt. Kinabalu—the highest mountain in southeast Asia—already have been demonstrated (Kitayama, 1996; Aiba and Kitayama, 1999). The accumulated stresses of climate change are likely to disrupt the ecology of mountain and highland systems.

11.2.1.2. Lakes/Streams, Rivers, and Glaciers

Lakes, streams, glaciers, and other freshwater ecosystems in Asia are highly diversified in terms of plant and animal species. These freshwater ecosystems have been stressed by environmental burdens, exploitation of natural resources, transformation of lands, and recreational activities. There is growing concern that climate change may accelerate the damage to freshwater ecosystems such as lakes, marshes, and rivers. More than 50,000 ha of coastal territories, including 35,000 ha of delta in the Selenga River and 12,000 ha of delta in the Upper Angara River, have been damaged during the past few years by precipitation and riverflow increases (Anokhin and Izrael, 2000). With an increased amount of precipitation likely in the future, more incidences of flooding and other adverse impacts are possible. With a rise in temperature, a decrease in the amount of snowfall in the Lake Biwa catchment in Japan is projected—which might exacerbate the process of eutrophication (Fushimi, 2000a). Deterioration of lake water quality also is suggested in Kasumigaura Lake in eastern Japan (Fujimoto *et al*., 1995; Fukushima *et al*., 2000). The response of lakes and streams to climate change will involve complex interactions between the effects of climate on areal inputs, hydrology, and catchments and in-lake processes.

Many of the major rivers in Asia have long been targets for development projects related to the hydroelectric, water supply, agriculture, industry, and navigation sectors. As a consequence, there have been shifts between freshwater and estuarine conditions as a result of high freshwater flows during the rainy season and low to nonexistent freshwater flows in the dry season. Increasing literol vegetation is causing health risks for local habitats in many countries of south Asia. Changes in aquatic habitat also have affected fisheries in lower valleys and deltas; the absence of nutrient-rich sediments has detrimental effects on fish productivity. Reduced flows in lower valley catchments also have resulted in eutrophication and poor water quality.

Many rivers originate from the glaciers in the Tianshan mountain range, which create wide alluvial fans at the foot of the northern Tianshan. The Hindukush Himalayan ranges are the source of some major rivers. The total amount of water flowing from the Himalayas to the plains of the Indian subcontinent is estimated at about 8.6×10^6 m^3 per year. The Himalayas have nearly 1,500 glaciers; it is estimated that these glaciers cover an area of about 33,000 km^2 (Dyurgerov and Meier, 1997). These glaciers provide snow and the glacial meltwaters keep major rivers perennial throughout the year. In recent decades, the hydrological characteristics of watersheds in this region seem to have undergone substantial change as a result of extensive land-use change—leading to more frequent hydrological disasters, enhanced variability in rainfall and runoff, extensive reservoir sedimentation, and pollution of lakes (Ives and Messerli, 1989). Almost 67% of the glaciers in the Himalayan and Tienshan mountain ranges have retreated in the past decade (Ageta and Kadota, 1992; Yamada *et al*., 1996; Fushimi, 2000b). The mean equilibrium-line altitude at which snow accumulation is equal to snow ablation for glaciers is estimated to be about 50–80 m higher than the altitude during the first half of the 19th century (Pender, 1995). Available records suggest that Gangotri glacier is retreating by about 30 m yr^{-1}. A warming is likely to increase melting far more rapidly than accumulation. As reported in IPCC (1998), glacial melt is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear.

11.2.1.3. Forests, Grasslands, and Rangelands

Most of the frontier forests in Asia are endangered today by rapid population growth, ever-increasing demand for agricultural land, poverty, poor institutional capacity, and lack of effective community participation in forestry activities (Mackenzie *et al*., 1998). Climate change is expected to affect the boundaries of forest types and areas, primary productivity, species populations and migration, the occurrence of pests and diseases, and forest regeneration. The increase in GHGs also affects species composition and the structure of ecosystems because the environment limits the types of organisms that can thrive and the amount of plant tissues that can be sustained (Melillo *et al.*, 1996). Compositional and structural changes, in turn, affect ecosystem function (Schulze, 1994). The interaction between elevated CO_2 and climate change plays an important role in the overall response of net primary productivity to climate change at elevated CO_2 (Xiao *et al*., 1998).

Climate change will have a profound effect on the future distribution, productivity, and health of forests throughout Asia (see also Section 5.6). Because warming is expected to be particularly large at high latitudes, climate change could have substantial impact on boreal forests (Dixon *et al*., 1996; IPCC, 1996; Krankina, 1997). Global warming will decrease permafrost areas, improve growing conditions, and decrease areas of disturbed stands and ecosystems in a general sense, although impacts would be significantly different at various locations within the boreal forests. Moreover, forest fire is expected to occur more frequently in boreal Asia as a result of increased mean temperature (Valendik, 1996; Lelyakin *et al*., 1997). Pest activity also could increase with a rise in temperature, depending on the age composition of the boreal forests (Alfiorov *et al*., 1998).

Asia's temperate forests are a globally important resource because of their high degree of endemism, biological diversity, ecological stability, and production potential. About 150 Mha of forests in central China have been cleared during the past several decades. Efforts are now underway to at least partially restore the area under forest cover in China through reforestation, soil recovery, and water conservation programs (Zhang *et al*., 1997). Studies on projected impacts of climate change suggest that northeast China may be deprived of the conifer forests and its habitat, and broad-leaved forests in east China may shift northward by approximately 3° of latitude. These results are based on a 2°C increase in annual mean temperature and a 20% increase in annual precipitation (Omasa *et al*., 1996; Tsunekawa *et al*., 1996).

Tropical moist forests have trees with higher densities of wood and larger proportions of branch wood relative to those in temperate forests. As many as 16 countries of tropical Asia are located within the humid tropical forest region. These forests and woodlands are important resources that must be safeguarded, given the heavy use of wood as fuel in some countries. Past policies in the humid tropics have focused mainly on natural forest protection and conservation (Skole *et al.*, 1998). However, there is a need to shift emphasis from conservation alone to a strategy that involves sustained development, investment performance, and public accountability (see Section 5.6). Encouragingly, the current annual rate of reforestation is highest in tropical Asia as a result of relatively high investments in reforestation schemes, including social forestry.

Most semi-arid lands in Asia are classified as rangelands, with a cover of grassland or scrublands. Although the share of land area used for agricultural purposes is about 82% of the total area, it is mainly low-productive pastures. With an increase in temperature of 2–3°C combined with reduced precipitation as projected for the future in the semi-arid and arid regions of Asia, grassland productivity is expected to decrease by as much as 40–90% (Smith *et al*., 1996). Approximately 70% of pastures are facing degradation, with dramatic decreases in fodder yield over recent decades in some parts of Mongolia (Khuldorj *et al*., 1998). Rangelands in Nepal also have been subject to degradation in recent years (NBAP, 2000). Climate change is likely to represent an additional stress to rapid social change in many of Asia's rangelands.

11.2.1.4. Drylands

Precipitation is scarce and has a high annual variance in dryland areas. Very high daily temperature variance is recorded with frequent sand storms, dust ghost, and intense sunshine. Arid plants usually belong to drought escaper, drought evader, drought resister, or drought endurer categories. Evaporative losses and water limitations are the most prominent factors dictating animal life in arid environments. Low rainfall dictates the formation of shallow or extremely sallow soils that often are characterized by high content of airborne particles and small fractions of rock-erosion elements. Most of the soils are poor in or completely devoid of organic matter, and the nutrient pools of the soils are low. Apparently, humans not only utilize the ecosystem services of this region but are also influencing the evolution of some of its important biotic elements. In Mongolia, for example, while soil fertility has decreased by about 20% in the past 40 years, about one-third of the pasturage has been overgrazed and 5 Mha of arid land have constantly been threatened by moving sands (Khuldorj *et al*., 1998). Soils exposed to degradation as a result of poor land management could become infertile as a result of climate change. Temperature increases would have negative impacts on natural vegetation in desert zones. Plants with surface root systems, which utilize mostly precipitation moisture, will be vulnerable. Climate change also would have negative impacts on sheep breeding and lamb wool productivity.

Just as shifts in vegetation belts are expected in non-drylands, in the drylands of Asia a shift in dryland types is expected as a result of climate change. Drylands are ranked along an aridity index, in relation to the ratio of precipitation to potential evapotranspiration (i.e., to a gradient in soil moisture available for driving production). Because soil moisture is likely to decline in this region, the least-dry land type (dry subhumid drylands) are expected to become semi-arid, and semi-arid land is expected to become arid. It is notable that population pressure on dryland resources is reduced with increasing aridity, but resistance to degradation and resilience following degradation also is reduced with increasing aridity. Therefore, semi-arid drylands, which are intermediate in aridity as compared to arid drylands and dry subhumid ones, are most susceptible to becoming further desertified (Safriel, 1995). Because semi-arid drylands are very common among Asian drylands, large areas will become not only dry but also desertified as a result of climate change,.

11.2.1.5. Cryosphere and Permafrost

Permafrost is highly responsive to climatic fluctuations at several temporal and spatial scales (Nelson and Anisimov, 1993). Evidence of spatially extensive episodes of permafrost thawing and poleward contraction has been documented (Halsey *et al*., 1995; Anisimov and Nelson, 1996b; Anisimov and Nelson, 1997; WASI, 1997). Depending on regional climate and local biological, topographic, and edaphic parameters, pronounced warming in the high latitudes of Asia could lead to thinning or disappearance of permafrost in locations where it now exists (Anisimov and Nelson, 1996a). Poleward movement of the southern boundary of the sporadic permafrost area is likely in Mongolia and northeast China. Large-scale shrinkage of the permafrost region in boreal Asia also is likely. In northern regions of boreal Asia, the mean annual temperature of permafrost, hence the depth of seasonal thawing (active layer thickness), will increase (Izrael *et al*., 1999). The perennially frozen rocks will completely degrade within the present southern regions (ICRF, 1998). The development of thermokarst and thermal erosion because of perennial thawing and increase in the depth of seasonal thawing of ice-rich grounds and monomineral ice accumulations is a critical process in permafrost regions of boreal Asia (Izrael *et al*., 1999). The change in rock temperature will result in a change in the strength characteristics, bearing capacity, and compressibility of frozen rocks, generation of thermokarst, thermal erosion, and some other geocryological processes (Garagulia and Ershov, 2000). In response to projected climate change, four main economic sectors in permafrost regions—surface and underground construction, the mining industry, heating energy demand, and agricultural development—will be affected (ICRF, 1995, 1998; Anisimov, 1999). Because large quantities of carbon are sequestered in the permafrost of boreal peatlands and tundra regions (Botch *et al*., 1995; Ping, 1996), changes in distribution of frozen ground and systematic increase in the thickness of seasonally thawed layer are likely to result in the release of large amounts of CO_2 and possibly methane (CH_4) into the atmosphere.

The permafrost area on the Tibetan Plateau has an average altitude of about 5,000 m and is one of the several regions not significantly affected by direct human activities. Because of this area's thermal and moisture conditions are on the edge of the ecological limitations of vegetation, it is believed to be highly sensitive to global warming (Zhang *et al.*, 1996). The boundary between continuous and discontinuous (intermittent or seasonal) permafrost areas on the Tibetan Plateau are likely to shift toward the center of the plateau along the eastern and western margins (Anisimov and Nelson, 1996b).

11.2.1.6. Protected Areas and Risks to Living Species

Protected areas usually are designated and managed to keep wild species that live within the area from becoming extinct. Even after an area has been set aside as protected habitat, extinction or population declines may still occur as a result of changes in environmental conditions related to climate change, land use in surrounding areas, or widespread pollution. Climate change is likely to induce vegetation change that will force wild plant and animal species to shift their distribution in response to the new conditions. For example, a variety of changes in butterflies, dragonflies, beetles, and other migratory insects have been recorded in green corridors of Japan in recent years (Ubukata, 2000), and shifts have been recorded in the ranges of many North American, European, Arctic, and Antarctic bird and insect species (see Section 5.4). If the protected area is not large enough to contain an area that will be suitable under the new climate conditions, a species may become locally extinct. In contrast, protected areas that are large enough to cover an elevation or a latitudinal gradient should allow species to make adjustments along the gradient as conditions change. In some cases, such as in coastal areas, habitat may simply be lost as a result of factors such as sea-level rise, with no potential area for species to migrate.

Frontier forests in Asia are home to more than 50% of the world's terrestrial plant and animal species (Rice, 1998). Risks to this rich array of living species are increasing. For instance, of the 436 species of mammals and 1,500 species of birds in Indonesia, more than 100 species each of mammals and birds have been declared threatened (UNEP, 1999). Similar trends also are seen in China, India, Malaysia, Myanmar, and Thailand. In India, as many as 1,256 higher plant species, of more than 15,000 species, are threatened (Sukumar *et al*., 1995).

Coastal areas are likely to be at risk from climate change-induced sea-level rise. A rise in the water level of estuaries will reduce the size and connectedness of small islands and coastal and estuarine reserves and increase their isolation. The Yangtze (Changjiang) and Mekong deltas on mainland China and the Mai Po marshes in Hong Kong are refueling stops for migratory birds, especially ducks, geese, and shorebirds. The presence of these birds may be threatened by the disappearance of coastal marshes as a result of increases in sea level from global warming (Li *et al.*, 1991; Tang, 1995). Similarly, the Rann of Kutch in India supports one of the largest Greater Flamingo colonies in Asia (Ali, 1985; Bapat, 1992). With sea-level rise, these salt marshes and mudflats are likely to be submerged (Bandyopadhyay, 1993), which would result in decreased habitat for breeding flamingoes and lesser floricans (Sankaran *et al.*, 1992). In addition, about 2,000 Indian wild asses in the Rann of Kutch could lose their only habitat in India to rising sea level (Clark and Duncan, 1992).

The Sundarbans of Bangladesh, which support a diversity of wildlife, are at great risk from rising sea level. These coastal mangrove forests provide habitat for species such as Bengal tigers, Indian otters, spotted deer, wild boars, estuarine crocodiles, fiddler crabs, mud crabs, three marine lizard species, and five marine turtle species (Green, 1990). With a 1-m rise in sea level, the Sundarbans are likely to disappear, which may spell the demise of the tiger and other wildlife (Smith *et al*., 1998).

Species that live in mountainous areas also are particularly at risk of losing habitat as a result of changes in climate. Extreme temperature conditions may cause these protected areas to undergo major changes, partly because of high rates of variation in habitat structure that naturally occur on mountain ranges as a result of changes in slope, steepness, and exposure. Protected areas also may be subjected to extreme surface runoffs because of rapid melting of winter snow. Because many Asian mountain ranges are east-west oriented, there will be little room for species to shift their ranges toward cooler mountainous habitat. An additional barrier to wildlife movements in mountainous habitat derives from the fact that many of the larger reserves in central Asia are located along international borders. Depending on topography, if these borders are heavily fenced, most of the larger terrestrial vertebrates will not be able to respond spatially to changes in their environment.

Besides loss of habitat, wild species are at risk from changes in environmental conditions that favor forest fires and drought. For example, forest fires under unseasonably high temperatures in Nepal may threaten local extinction for red pandas, leopards, monkeys, deer, bears, and other wild animals. If the frequency of these extreme events increases, the frequency of fire also may increase. Similarly, increases in the frequency of dry spells and local droughts may decrease populations. For example, drought-related decreases in the density and persistence of Green Leaf Warblers have been recorded on their wintering grounds in the Western Ghats of south India (Katti and Price, 1996). In desert ecosystems, protected areas often are located around oases, which are the basis for the existence of much of the local fauna. Protected oases often are far apart, so droughts that cause a decline in local forage often cause mass mortality because animals may not be able to move on to adjacent oases. The frequency of these droughts therefore is a key component in the viability of populations in such protected areas (Safriel, 1993).

Climate change is likely to act synergistically with many other stressors, such as land conversion and pollution, leading to major impacts on protected areas and species (see Chapter 5). Currently designated major protected areas in Asia need to be examined with respect to the ability of their species to shift in range in response to changing climate, as well as with respect to how much habitat could be lost. Many species—especially those in coastal areas and mountainous habitats—could experience large population declines; some may become extinct at least in part because of climate changes.

11.2.2. Agriculture and Food Security

11.2.2.1. Production Systems

Asia has the world's largest area under cereal cultivation and is the largest producer of staple foods (FAO, 1999a). Present crop yields in Asia are comparable to those in Europe and South America. Within Asia, India has the largest area under cereal cultivation. The total production of cereals in China is twice that of India, as a result of higher average productivity (FAO, 1999a). Most land that is suitable for cultivation is already in use; by 2010 per capita availability of land in developing countries of Asia will shrink from the present 0.8 ha to about 0.3 ha. Table 11-4 depicts the growth rate of rice cultivation area in select Asian countries. Current rates of land degradation suggest that a further 1.8 million km^2 of farmland could become unproductive in Asia by 2050, adding stress to a system that must ensure food security in the context of a rapidly growing population.

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.

***Table 11-4**: Changes in area under rice cultivation in select Asian countries, 1979–1999 (FAO, 1999a).*

Country	**Period**	**Total Rice Cultivation Area (10^3 ha)**	**Change in Rice Cultivation Area (10^3 ha)**	**Rate of Change in Rice Cultivation Area (ha yr^{-1})**
Bangladesh	1979	10,160	310	14,762
	1999	10,470		
Cambodia	1979	774	1,187	56,524
	1999	1,961		
China	1979	34,560	-2,840	-135,238
	1999	31,720		
India	1979	39,414	3,586	170,762
	1999	43,000		
Indonesia	1979	8,804	2,820	134,286
	1999	11,624		
Malaysia	1979	738	-93	-4,429
	1999	645		
Myanmar	1979	4,442	1,016	48,381
	1999	5,458		
Nepal	1979	1,254	260	12,381
	1999	1,514		
Sri Lanka	1979	790	39	1,857
	1999	829		
Pakistan	1979	2,035	365	17,381
	1999	2,400		
Philippines	1979	3,637	341	16,238
	1999	3,978		
Thailand	1979	8,654	1,346	64,095
	1999	10,000		
Vietnam	1979	5,485	2,163	103,000
	1999	7,648		

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 CO_2 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 (see also Chapter 5). 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 CO_2 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 CO_2 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 CO_2 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 CO_2 in the future.

Key findings on the impacts of an increase in surface temperature and elevated CO_2 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. 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 CO_2 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.

***Table 11-5**: Model-simulated mean change (%) in potential yields of rice in Asia under fixed increments of air temperature and ambient CO_2 level (Matthews et al., 1995b).*

Model Used and Ambient CO_2 Levels	**Percent Change in Mean Potential Rice Yield in Asia resulting from Surface Air Temperature Increment of**			
	0°C	+1°C	+2°C	+4°C
ORYZA1 Model				
340 ppm	0.00	-7.25	-14.18	-31.00
1.5xCO_2	23.31	12.29	5.60	-15.66
2xCO_2	36.39	26.42	16.76	-6.99
SIMRIW Model				
340 ppm	0.00	-4.58	-9.81	-26.15
1.5xCO_2	12.99	7.81	1.89	-16.58
2xCO_2	23.92	18.23	11.74	-8.54

11.2.2.2. Grain Supply and Demand in Asia

Asia's total cereal production more than tripled between 1961 and 1999, from 329.5 to nearly 1,025.8 Mt; the increase in harvest area was only marginal (from 271.8 to 324.5 Mha) during this period. Rice paddy production in Asia jumped from 198.7 to 533.5 Mt while the harvest area increased from 106.9 Mha in 1961 to 136.5 Mha in 1999. Similarly, wheat production in Asia increased from 45.8 to 261.7 Mt while the harvest area increased from 61.2 Mha in 1961 to 97.2 Mha in 1999. A three-fold increase in production of sugarcane and almost five-fold increase in oil crops took place in Asia during 1961–1999. Asian production of starchy roots also doubled during this period. Even as the Asian population increased a little more than two-fold—from 1.70 billion to 3.58 billion people—during this time, per capita consumption of calories in Asia has increased since the 1960s (FAO, 1999a). This improvement in the food situation has been the consequence of an increase in production, resulting from technological advances, that has outpaced population growth in Asia. However, because there is a limit to the amount of arable land, while the Asian population continues to grow, the per capita area of harvest has consistently decreased.

The population growth rate has been a primary factor in the increase in demand for food grains in Asia. Since the mid-1980s, rapid changes in food supply and demand structures have been observed in most developing countries. Declines in self-sufficiency for grains have been particularly dramatic in countries with advanced economies, such as Japan, South Korea, Taiwan (China), and Malaysia, where the grain self-sufficiency rate has fallen below 30% in recent years. The rapid decline in grain self-sufficiency in these countries is unprecedented in any region of the world. Between 1970 and 1996, grain self-sufficiency fell from 45 to 27% in Japan, from 68 to 31% in Korea, from 61 to 19% in Taiwan (China), and from 60 to 25% in Malaysia (FAO, 1996). Declines in grain self-sufficiency also have been observed in the Philippines, Indonesia, and Sri Lanka. Populous countries such as China, India, Bangladesh, and Pakistan have long maintained grain self-sufficiency of more than 90%, but as these countries shift to industrialization it is possible that declines will be observed there as well. In contrast, Thailand and Vietnam, which encompass the great grain-producing regions of the Menam and Mekong River deltas, continue to maintain better than 100% self-sufficiency for grains.

The annual per capita consumption of meat in principal Asian countries also has shown an upward trend in recent years. Since the 1970s, South Korea and China have reported the most rapid increases in meat consumption. In South Korea, per capita meat consumption grew about seven-fold, from 5.2 to 40 kg between 1970 and 1997; in China, it increased nearly five-fold, from 8.8 to 42.5 kg. During the same period, per capita meat consumption more than doubled in Japan (42.2 kg in 1997) and Malaysia (51.9 kg in 1997). Meat consumption in Sri Lanka, Bangladesh, and India grew only marginally, remaining below or at 5 kg even in 1997—considerably lower than the level in east Asia. The increasing trend in meat consumption in temperate Asia means higher demand for livestock feed for the production of meat. Demand for this feed in Asia increased from 25.2 Mt in the 1970s to 61.2 Mt in 1980, 147.0 Mt in 1990, and 163.0 Mt in 1999. The demand for feed grain in Asia has grown at an annual rate of about 6.6% and has been a principal factor in the rapid increase in demand for world grain imports.

The world is moving toward a tighter grain supply and demand, and instability in the world grain market is rising. At the same time, Asia is becoming increasingly dependent on the world grain market. As shown in Figure 11-8, net grain import in Asia was 20.3 Mt in 1961; it increased to 80.9 Mt by 1998. The continuing increase in grain imports is a result of increasing

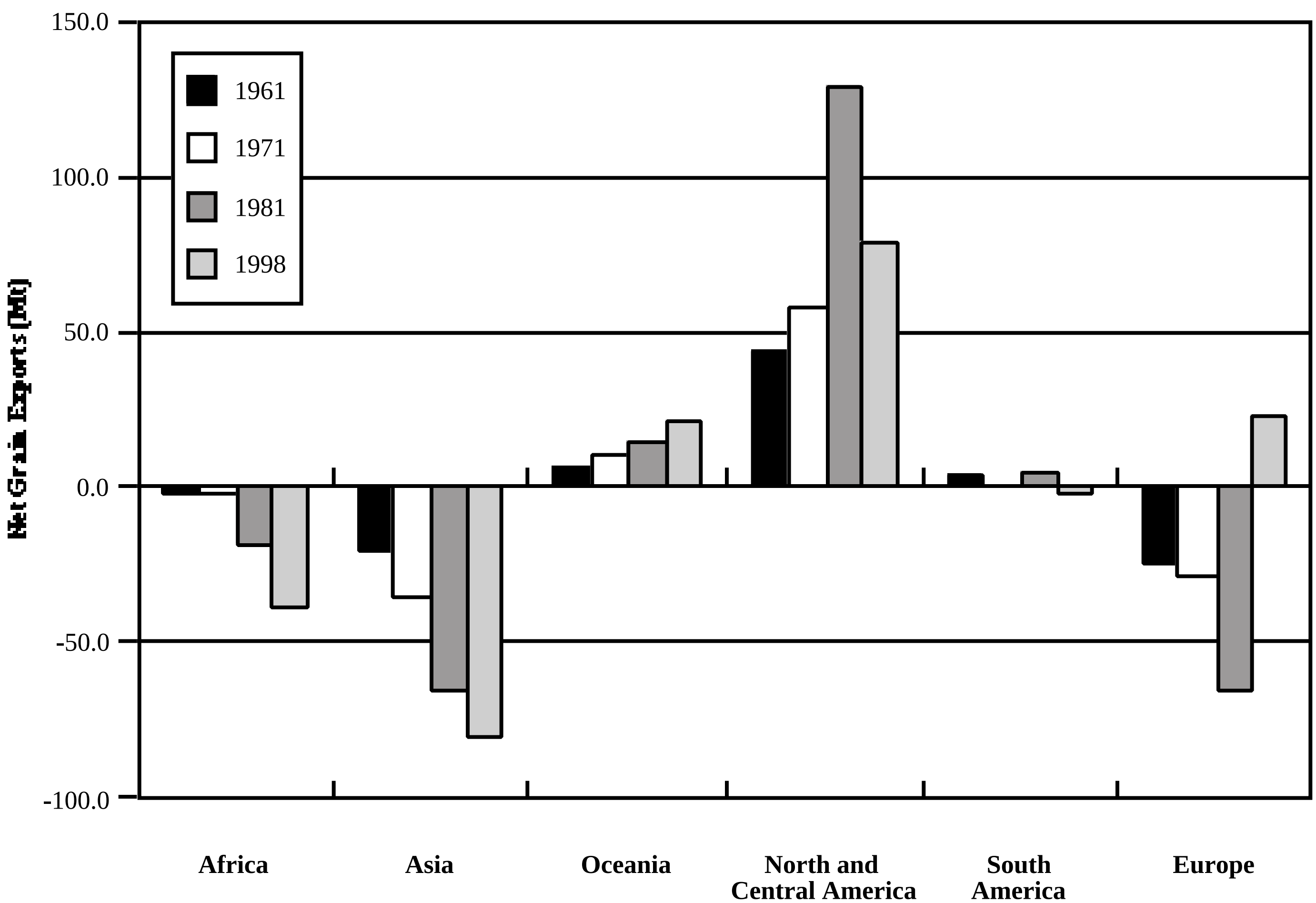

Figure 11-8: Trends in net grain exports in major world regions (USDA, 1999).

populations and increased demand for grain that accompanies economic growth, with which increases in grain production within the region cannot keep pace.

The impact of global warming on the international supply and demand of rice and wheat has been evaluated by Nakagawa *et al*. (1997) through the use of a partial equilibrium-type dynamic model for world supply and demand. Based on a world rice and wheat supply and demand model and a unit harvest scenario, the study projected that the serious impacts of global warming would be felt as early as the year 2020. The study suggests that the early impacts will not be so severe that humans are unable to control them. However, the gap between supply and demand may grow in some regions of Asia, resulting in considerably increased reliance on imports. Furthermore, the problem of short-term fluctuations in the market because of an increased frequency of droughts, floods, and other extreme weather events will be exacerbated, making it necessary to promote measures to combat climate change on a global scale.

11.2.2.3. Food Security

A major new challenge in future food production to meet the demand of the growing Asian population is in coping with the changing environment, which may alter the current optimum

Table 11-6*: Prevalence of undernourishment in developing countries of Asia (FAO, 1999a; UNICEF, 1999).*

Country/Region	Popu-lation, 1996 (millions)	Main Cereal Consumed, 1995–1997	Dietary Energy Supply per Person, 1995–1997 (kcal day^{-1})	Access to Adequate Sanitation, 1990–1997 (%)	Under 5 Mortality Rate, 1995 (per1000)	Numberof Under-nourished People (millions)	Fraction of Population Under-nourished, 1979–1981 (%)	Fraction of Population Under-nourished, 1995–1997 (%)
Arid and Semi-Arid Asia								
– Afghanistan	20.3	Wheat	1730	8	257	12.7	33	62
– Iran	63.5	Wheat	2830	81	40	3.7	9	6
– Iraq	20.6	Wheat	2370	75	71	3.2	4	15
– Jordan	4.4	Wheat	2910	77	25	0.1	6	3
– Kuwait	1.7	Wheat	3060	—	14	0.1	4	3
– Lebanon	3.1	Wheat	3270	63	40	0.1	8	2
– Pakistan	140.1	Wheat	2460	56	137	26.3	31	19
– Saudi Arabia	18.9	Wheat	2800	86	34	0.7	3	4
– Syrian Arab Republic	14.6	Wheat	3330	67	36	0.2	3	1
– Turkey	62.3	Wheat	3520	80	50	1.0	2	2
– United Arab Emirates	2.3	Rice/Wheat	3360	92	19	0.0	1	1
Temperate Asia								
– China	1238.8	Rice	2840	24	47	164.4	30	13
– Korea, DPR	22.6	Maize/Rice	1980	—	30	10.8	19	48
– Korea, Republic	45.3	Rice	3160	100	9	0.4	1	1
– Mongolia	2.5	Wheat	1920	86	74	1.2	27	48
South Asia								
– Bangladesh	120.6	Rice	2080	43	115	44.0	42	37
– India	950.0	Rice	2470	29	115	204.4	38	22
– Nepal	21.8	Rice	2320	16	114	4.6	46	21
– Sri Lanka	18.1	Rice	2290	63	19	4.6	22	25
Southeast Asia								
– Cambodia	10.2	Rice	2050	19	174	3.4	62	33
– Indonesia	200.4	Rice	2900	59	75	11.5	26	6
– Laos	4.9	Rice	2060	18	134	1.6	32	33
– Malaysia	20.5	Rice	2940	94	13	0.4	4	2
– Myanmar	43.4	Rice	2850	43	150	2.8	19	7
– Philippines	69.9	Rice	2360	75	53	15.6	27	22
– Thailand	59.2	Rice	2350	96	32	14.3	28	24
– Vietnam	75.1	Rice	2470	21	45	14.1	33	19

Box 11-2. Bangladesh: Food Insecurity in an Agrarian Nation

Malnutrition remains endemic in Bangladesh, an overwhelmingly agrarian country where most rural households do not own land and have few other opportunities to earn wage income. At barely 2,000 kilocalories per person per day, food availability falls short of meeting basic requirements. With extensive poverty, malnutrition, inadequate sanitation, and inadequate access to health care, the country is vulnerable to outbreaks of infectious, water-borne, or other types of diseases. Less than half the population of Bangladesh currently has access to adequate sanitation. Some areas of the country still face the risk of famine; others have frequent floods and often are devastated by cyclones and storm surges.

Overall, the rate of undernourishment is very high (37%), as is the prevalence of underweight, stunting, and wasting among children (Figure 11-9). Rates are high throughout the rural areas that are home to 80% of Bangladesh's population. More than 60% of rural households are functionally landless, and there are limited opportunities for income diversification (Mimura and Harasawa, 2000). The level of vulnerability is likely to increase as a result of severe land degradation, soil erosion, lack of appropriate technology, and the threat of sea-level rise from global warming. Climate change could result in a decreased supply of water and soil moisture during the dry season, increasing the demand for irrigation while supply drops. Improving irrigation efficiency and agricultural productivity will help make Bangladesh self-sufficient in crop production and reduce malnourishment. Higher yields may enable the country to store food supplies to carry it through low-harvest years (Azam, 1996). A switch to growing higher value crops and expansion of free market reforms in agriculture may enable Bangladesh to sell more crops for export. Diversification should help in providing robustness to withstand climate change and variability.

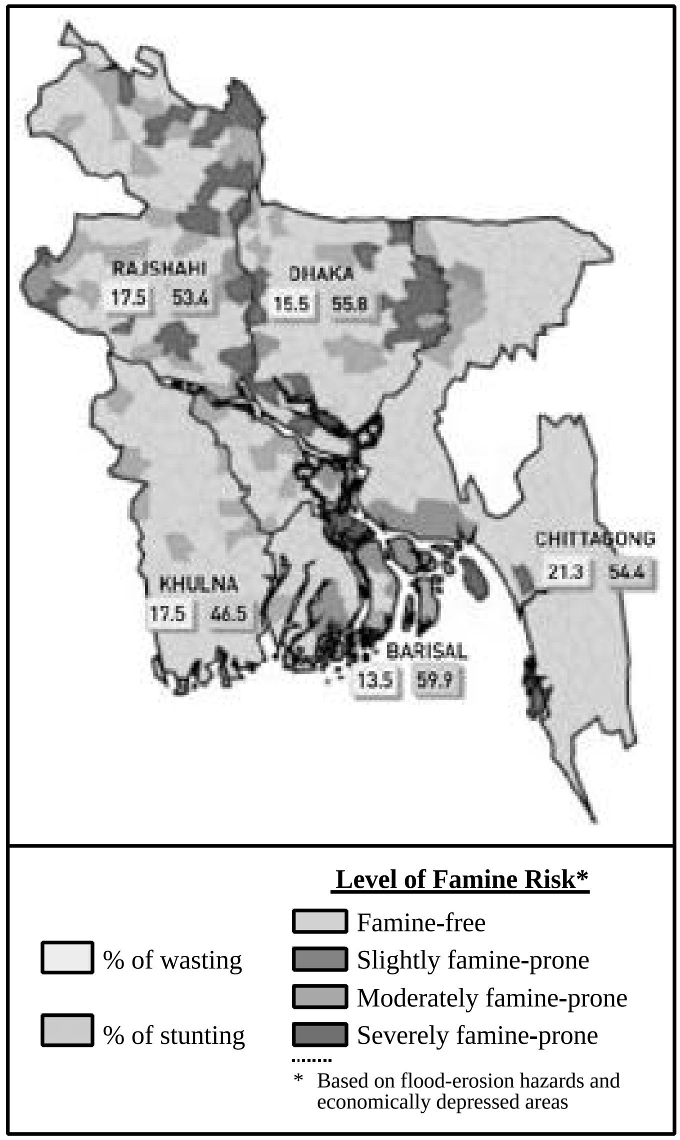

Figure 11-9: Food insecurity and malnutrition in Bangladesh (FAO, 1999b).

growing requirement of agricultural crops. The potential impacts of climate change on agriculture in Asia are crucial because of agriculture's ultimate role in providing food and fiber to Asia's human population. Countries in south and southeast Asia have shown strong reductions in undernourished population in the 1990s. Even so, it has been estimated that almost two-thirds (more than 500 million) of undernourished people live in developing countries of Asia and the Pacific. South Asia accounts for more than one-third of the world total (258 million). Another 64 million undernourished people live in southeast Asia; more than 160 million live in China (FAO, 1999b). The undernourished population almost doubled between 1995 and 1999—from 6 to 12%—as a result of the economic crisis in Indonesia. With the highest incidences of undernutrition and a very large population of children under the age of five, south Asia accounts for almost half of the world's underweight and stunted children (see Box 11-2). Table 11-6 lists the prevalence of undernourishment in Asian developing countries.

Ongoing studies on crop productivity in relation to global warming cover not only biophysical aspects but also socioeconomic drivers and consequences (Fischer *et al*., 1995; Islam, 1995). The economic impacts of climate change on world agriculture are expected to be relatively minor because decreasing food production in some areas will be balanced by gains in others (e.g., Kane *et al*., 1991; Tobey *et al*., 1992; Rosenzweig and Parry, 1993). Such findings however, should be viewed as aggregate results that mask crucial differences in inter-country and intra-country production impacts and the distribution of food resources. In Asia, where rice is one of the main staple foods, production and distribution of rice-growing areas may be affected substantially by climate change. Disparity between rice-producing countries is already visible, and it is increasingly evident between developed and developing countries (Fischer *et al*., 1996). The projected decline in potential yield and total production of rice in some Asian countries because of changes in climate and climate variability would have a significant effect on trade in agricultural commodities, hence on economic growth and stability (Matthews *et al*., 1995b)

Increasing population growth and changing dietary patterns in Asia have resulted in more and more land moving from forests and grasslands into agricultural production. Regardless of the increased use of chemical fertilizers and pesticides, in addition to changes in irrigation practices and improved seed stock, yields for major cereal crops have stagnated in many Asian countries during recent years (Iglesias *et al*., 1996; Sinha, 1997); further intensification of agriculture on area in cropland is certain, and conversion of more land to agricultural use is likely, especially in the developing countries of Asia. Both actions will have far-reaching implications with regard to increased soil erosion, loss of soil fertility, loss of genetic variability in crops, and depletion of water resources (Sinha *et al.*, 1998). Soil degradation is seemingly irreversible unless remedied through painstaking reconstruction of soil health.

A clear understanding of the relationship between climatic variability, crop management, and agricultural productivity is critical in assessing the impacts of climatic variability and change on crop production, the identification of adaptation strategies and appropriate management practices, and the formulation of mitigating measures to minimize the negative effects of climatic variability (including extreme events) on agricultural productivity. In the future, food security will be at the top of the agenda in Asian countries because of two emerging events: growing population, and many direct and indirect effects of climate change. Greatly enhanced efforts to understand the relationship between key climate elements and agriculture should provide a sound basis for meeting the challenges of optimizing the benefits of changing climatic resources.

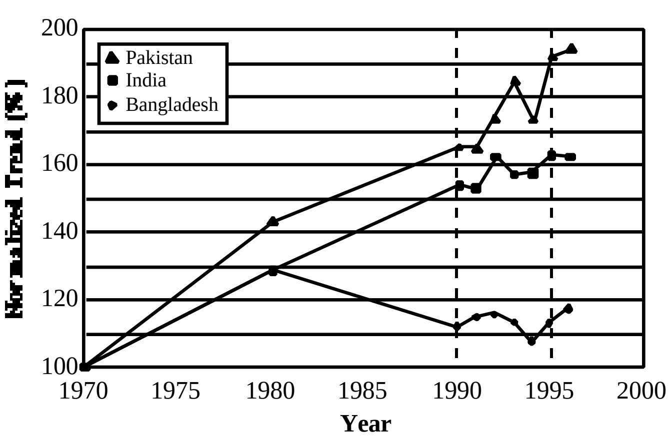

Figure 11-10: Normalized trends in grain production in Bangladesh, India, and Pakistan since 1970 (CIA, 1998).

In some Asian countries, the pace of food grain production has slowed in recent years as a result of depletion of soil nutrients and water resources, creation of salinity and waterlogging, resurgence of pests and diseases, and increased environmental pollution (Gadgil, 1995). Many natural as well as environmental factors—such as extremely dry or cold climates, erratic rainfall, storms and floods, topsoil erosion and severe land degradation, and poor investment and lack of appropriate technology—have played limiting roles in the agricultural potential of most developing countries of Asia (see also Section 5.3). For example, food grain production in Pakistan and India has continued to increase since the 1970s while it has stagnated in Bangladesh (Figure 11-10), largely because of increased losses to climate extremes and land degradation. In India, the estimated total requirement for food grains would be more than 250 Mt by 2010; the gross arable area is expected to increase from 191 to 215 Mha by 2010, which would require an increase of cropping intensity to approximately 150% (Sinha *et al.*, 1998). Because land is a fixed resource for agriculture, the need for more food in India could be met only through higher yield per units of land, water, energy, and time—such as through precision farming. To ensure food security in the developing countries of south and southeast Asia, it is necessary to expand agricultural production, develop the food distribution system, and promote nutrition education, as well as expand the economy and adjust the distribution of incomes.

11.2.3. Hydrology and Water Resources

11.2.3.1. Water Availability

One-third of the world's renewable water resources (13,500 km^3 yr^{-1} out of 42,700 km^3 yr^{-1}) are concentrated in Asia (Shiklomanov, 2001). Water availability varies widely across the different regions of Asia, however—from 77,000 m^3 yr^{-1} per capita to less than 1,000 m^3 yr^{-1} per capita. Table 11-7 provides available information on renewable local water resources, water availability, and water use dynamics by natural-economic region of Asia. The major share of Asian water resources (72%) is located in four countries: Russia (3,107 km^3 yr^{-1}), China (2,700 km^3 yr^{-1}), Indonesia (2,530 km^3 yr^{-1}), and India (1,456 km^3 yr^{-1}). Water resources of the two largest river systems of Asia—the Ganges (with Brahmaputra and Meghna) and the Yangtze (Changjiang)—attain 1,389 km^3 yr^{-1} (794 x 10^3 m^3 yr^{-1} km^{-2}) and 1,003 km^3 yr^{-1} (554 x 10^3 m^3 yr^{-1} km^{-2}). Figure 11-11 depicts the spatial distribution of currently estimated annual mean surface runoff over Asia. The runoff distribution within a year in Asia is most uniform in the rivers of southeast Asia. Over the rest of the continent, more than half of the annual runoff is discharged during the three summer months.

Water availability—in terms of temporal as well as spatial distribution—is expected to be highly vulnerable to anticipated climate change. Growing populations and concentration of population in urban areas will exert increasing pressures on water availability and water quality. As reported in IPCC (1998), runoff generally is expected to increase in the high latitudes and near the equator and decrease in the mid-latitudes under anticipated climate change scenarios.

An assessment of implications of climate change for global hydrological regimes and water resources, using climate change scenarios developed from Hadley Centre model simulations (Arnell, 1999), allows examination of the potential impacts on Asia. A macro-scale hydrological model was used to simulate river flows across the globe at a spatial resolution of 0.5°x0.5°, covering regions of 1,800–2,700 km². The study suggests that average annual runoff in the basins of the Tigris, Euphrates, Indus, and Brahmaputra rivers would decline by 22, 25, 27, and 14%, respectively by the year 2050. Runoff in the Yangtze (Changjiang) and Huang He Rivers have the potential to increase as much as 37 and 26%, respectively. Increases in annual runoff also are projected in the Siberian rivers: the Yenisey (15%), the Lena (27%), the Ob (12%), and the Amur (14%). Areas with particularly large percentage change in high flows include temperate Asia. Significant changes in monthly runoff regimes also are projected over most of Asia.

Some areas of the Asian continent are expected to experience increases in water availability; other areas will have reduced water resources available. Surface runoff is projected to decrease drastically in arid and semi-arid Asia under climate change scenarios and would significantly affect the volume of water available for irrigation and other purposes. Sensitivity

***Table 11-7**: Renewable local water resources, water availability, and water-use dynamics, by natural-economic regions of Asia (Shiklomanov, 2001).*

Region	Area (10^6 km²)	Water Resources (km³ yr^{-1})	Potential Water Availability (10^3 m³ yr^{-1})		Dynamics of Freshwater Use (km³ yr^{-1})[a]			Forecast			Water Use as a Percentage of Water Resources[a]	
			per km²	per capita	1900	1950	1995	2000	2010	2025	1995	2025
Siberia and far east of Russia	12.76	3107	243	76.6	0.7/0.4	5.6/1.3	30.6/15	30/15	32/17	38/21	1.0/0.5	1.2/0.6
North China and Mongolia	8.29	1029	124	2.13	37/30	98/75	254/182	273/185	305/194	373/210	24.7/17.7	36.2/20.4
South Asia	4.49	1988	443	1.77	201/160	367/293	932/687	969/710	1060/767	1370/944	43.6/32.1	64.1/44.2
Southeast Asia	6.95	6646	956	4.77	99/77	230/170	525/388	551/393	617/413	781/425	7.8/5.8	11.6/6.3
Western Asia	6.82	490	71.8	2.11	43/34	91/71	238/174	248/181	283/201	346/229	48.5/35.5	70.6/46.7
Central Asia and Kazakhstan	3.99	181	45.4	3.78	29/19	57/37	154/102	151/102	160/110	169/122	75.5/50.0	82.8/59.8
Transcaucasia	0.19	67.9	358	4.63	4.2/2.1	11.4/7.1	23.7/17.5	23/17	26/19	27/20	32.0/23.7	36.5/27.0
Total	43.50	13510	311	3.92	414/322	860/654	2157/1565	2245/1603	2483/1721	3104/1971	16.0/11.6	23.0/14.6

[a]Nominator = total water withdrawal; denominator = water consumption.

analysis of water resources in Kazakhstan to projected climate change scenarios indicates that surface runoff would be substantially reduced as a result of an increase in surface air temperature of 2°C accompanied by a 5–10% decline in precipitation during summer (Gruza *et al*., 1997). In temperate Asia, future changes in surface runoff would be highly spatially inhomogeneous. An increase in surface runoff seems likely in Mongolia and northern China. The hydrological characteristics

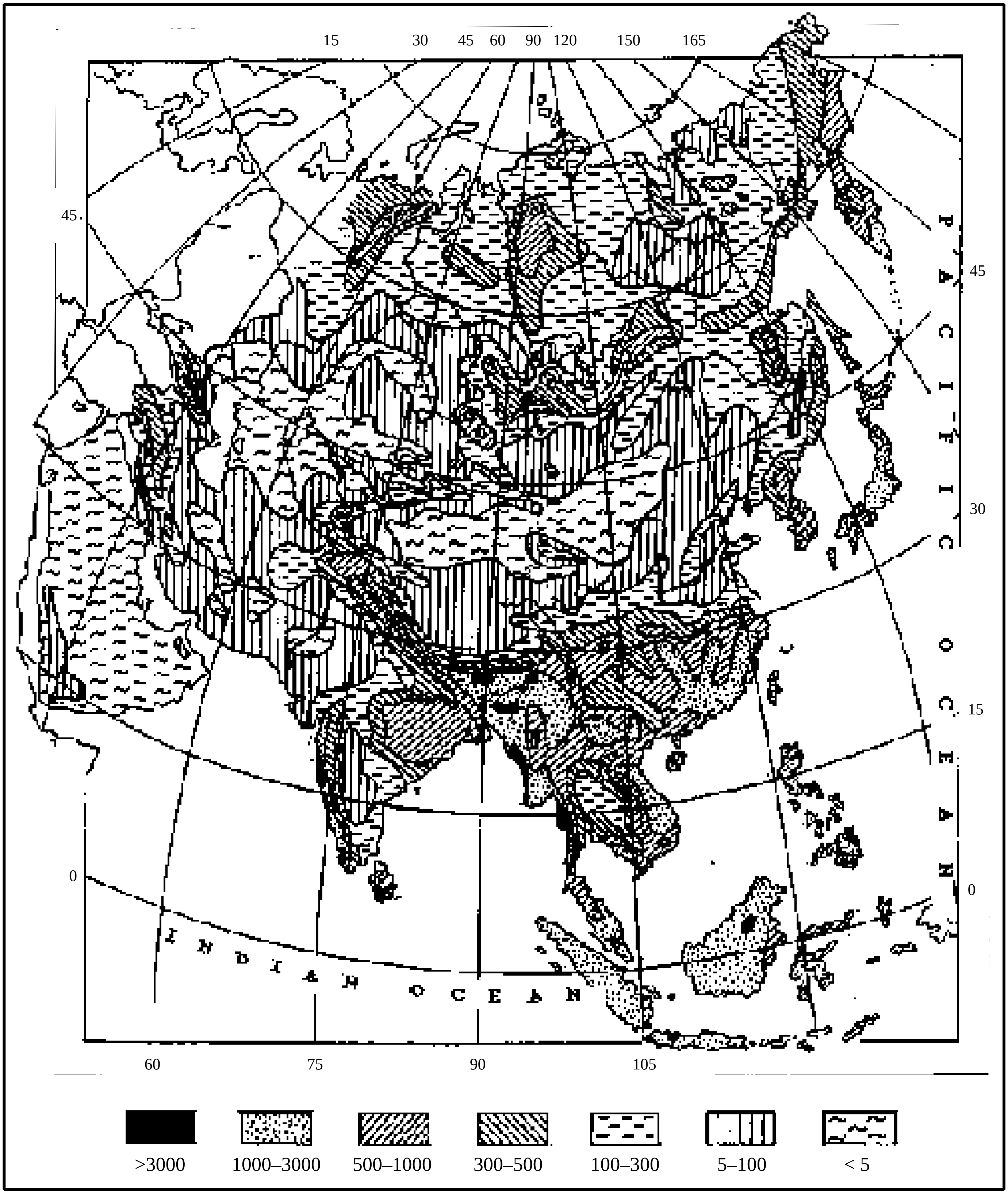

Figure 11-11: Spatial distribution of currently estimated surface runoff (mm) over Asian continent (Shiklomanov, 2001).

of Japanese rivers and lakes also are sensitive to climate change. Recent studies suggest that, on average, a 3°C increase in temperature coupled with a 10% increase in precipitation will increase river flows by approximately 15% in water-abundant areas. An increase in temperature also accelerates snow melting, which increases river flows from January through March but decreases flows from April through June (Hanaki *et al*., 1998; Inoue and Yokoyama, 1998).

The perennial rivers originating in the high Himalayas receive water from snow and glaciers. Snow, ice, and glaciers in the region are approximately equivalent to about 1,400 km^3 of ice. The contribution of snow to the runoff of major rivers in the eastern Himalayas is about 10% (Sharma, 1993) but more than 60% in the western Himalayas (Vohra, 1981). Because the melting season of snow coincides with the summer monsoon season, any intensification of the monsoon is likely to contribute to flood disasters in Himalayan catchments. Such impacts will be observed more in the western Himalayas compared to the eastern Himalayas because of the higher contribution of snowmelt runoff in the west (Sharma, 1997). An increase in surface runoff during autumn and a decrease in springtime surface runoff are projected in highland regions of south Asia. The increase in surface temperature also will contribute to a rise in the snowline—which, in effect, reduces the capacity of the natural reservoir. This situation will increase the risk of flood in Nepal, Bangladesh, Pakistan, and north India during the wet season (Singh, 1998). No significant changes are projected for annual mean surface runoff in southeast Asia; an increase during winter and a decrease during summer season is likely, however.

Available data on the dynamics of freshwater use by natural-economic regions of Asia (Table 11-8) suggest that freshwater use—in terms of total water withdrawal and water consumption—have increased significantly in recent decades in all regions and is projected to increase further in the 21st century. Table 11-8 also suggests that water use in most regions of Asia (except Russia and southeast Asia) already has exceeded 20% of the available resources (Arnell, 1999) and will be increasing appreciably by 2025. It follows from this table that water is going to be a scarce commodity in Asia in the near future even without the threat of climate change.

11.2.3.2. Water Needs and Management Implications

At present, approximately 57% of total water withdrawal and 70% of water consumption in the world occurs within the countries of Asia. Table 11-8 presents the dynamics of freshwater use in Asia over the sectors of economic activities. As is evident from this table, agriculture (irrigation in particular) accounts for 81% of total water withdrawal and 91% of water consumption in Asia. The area of irrigated lands in Asia currently amounts to 175 Mha and may increase to 230 Mha by 2025. As Table 11-7 implies, the two most populated regions of south and southeast Asia account for about 68% of water withdrawal and about 69% of water consumption in Asia (see Chapter 4). More than

Table 11-8: *Dynamics of freshwater use in Asia over sectors of economic activities, $km^3\ yr^{-1}$ (Shiklomanov, 2001).*

	Assessment				Forecast		
	1900	1950	1970	1995	2000	2010	2025
Population (million)		1464	2103	3498	3762	4291	4906
Irrigation area (Mha)	36.1	72.5	118	175	182	199	231
Water use[a]							
– Agriculture	408/320	816/643	1331/1066	1743/1434	1794/1457	1925/1553	2245/1762
– Industry	4/1	33/6	107/13	184/30	193/32	248/40	409/58
– Domestic	2/1	11/5	38/14	160/31	177/33	218/36	343/44
– Reservoirs (evaporation)	0	0.23	23	70	81	92	107
Total	414/322	860/650	1499/1116	2157/1565	2245/1603	2483/1721	3104/1971

[a]Nominator = total water withdrawal; denominator = water consumption.

75% of the total water available in India currently is used for irrigation. As much as 20% is required to meet domestic and municipal needs—leaving just 5% for industrial needs. The only river in north India that has surplus water to meet future needs of the country is the Brahmaputra. This river, however, is an international river; other countries such as Bangladesh may not approve of building a dam across some of its tributaries. In peninsular India, only the Mahanadi and Godavari have surplus water, but conveying it to drought-prone areas of the south is problematic. Many states in India need to adopt measures for restricting the use of groundwater to prevent a water famine in the future. China's rapid economic growth, industrialization, and urbanization—accompanied by inadequate infrastructure investment and management capacity—have contributed to widespread problems of water scarcity throughout the country. Of the 640 major cities in China, more than 300 face water shortages; 100 face severe scarcities (UNDP, 1997).

Taking into account projected dynamics of economic development in the temperate, tropical, and arid and semi-arid regions of Asia, combined with the climate change-imposed effect on hydrological regimes, agriculture and the public water supply would require priority attention in these regions to secure sustainable development and avoid potential intersectoral and international water conflicts. Radical changes in water management strategies and substantial investments will be required in Asia to cope with water problems in the 21st century. Adaptation measures will include legal, institutional, and technical initiatives such as modifying existing and constructing new infrastructure (reservoirs, interbasin water transfer schemes), introducing water-saving technologies, upgrading efficiency of irrigation systems, enhancing wastewater recycling systems, introducing low water-use crops, and implementing groundwater protection programs.

At least 14 major international river watersheds exist in Asia. An integrated and decentralized system of restoration and conservation of the water cycle in these drainage basins is vital to mitigate the negative consequences of natural and externally imposed perturbations. Watershed management is challenging in countries where the people-to-land ratio is high and policy and management are inadequate, prompting use of even the most fragile and unsuitable areas in the watersheds for residential, cultivation, and other intensive uses. This is particularly true for countries such as Bangladesh, Nepal, the Philippines, Indonesia, and Vietnam, where many watersheds suffer badly from deforestation, indiscriminate land conversion, excessive soil erosion, declining land productivity, erratic and unreliable surface and groundwater resources, and loss of biodiversity. Many watersheds in Asia already are stressed by intensive use of the land and other resources and by inhospitable climate (especially in arid and semi-arid Asia), beyond their ability to adequately supply water, prevent floods, and deliver other goods and services. In the absence of appropriate adaptation strategies, these watersheds are highly vulnerable to climate change. Global climate change also may have serious water management implications on the territory of boreal Asia. Recent assessments (Izrael *et al*., 1997a; CAFW, 1998) for all major Siberian rivers (Ob, Yenisei, Lena) with 42% of the total freshwater inflow to the Arctic ocean show that the main water management problems by the year 2050 will be a consequence of significant annual runoff increases (up to 20%) and difficulties with seasonal inundation and flood control measures.

11.2.4. Oceanic and Coastal Ecosystems

11.2.4.1. Oceans and Coastal Zones

In line with global trends, more than half of the region's population—1.7 billion people—presently resides in the coastal zone of Asia (Middleton, 1999). Given the relentless and cumulative process of global environmental change driven by, among other factors, demographic changes, urbanization and industrial development, trade and transport demands, and lifestyle changes, the coastal zones of Asia are under increasing anthropogenic pressures (Turner *et al*., 1996). The consequences of this process pose a significant threat to environmental and socioeconomic systems located in Asian coastal zones. All coastal areas are facing an increasing range of stresses and shocks, the scales of which now pose a threat to the resilience of human and environmental coastal systems and are likely to be exacerbated by climate change.

Climate impacts on coastal zones of Asia include accelerated sea-level rise and more frequent and severe storm events. Large populations in coastal areas of southeast and south Asia are vulnerable to pressure from unsustainable resource use and environmental degradation (e.g., Dow, 1999). These areas already are subject to numerous climate change-related stresses, including loss of coastal mangroves that act as major environmental determinants of coastal fisheries (Daily, 1997; Field *et al*., 1998; Primavera, 1998). Major delta areas of Asia are likely to be subjected to stresses associated with sea-level rise, changes in water regimes, saltwater intrusion, siltation, and land loss (see Chapter 6). Low-lying coastal cities will be at the forefront of impacts; these cities include Shanghai, Tianjin, Guangzhou, Jakarta, Tokyo, Manila, Bangkok, Karachi, Mumbai, and Dhaka—all of which have witnessed significant environmental stresses in recent years. Jakarta, Bangkok, and Tianjin, for example, have experienced changes in relative sea level of as much as 5 cm yr^{-1} during the 1980s and 1990s as a result of subsidence associated with groundwater withdrawal (ESD-CAS, 1994; Nicholls, 1995). In addition, increases in temperature can lead to increased eutrophication in wetlands and freshwater supplies.

Tropical Asia experiences the impact of present-day climate variability associated with ENSO, therefore is more prone to changes in ENSO-related impacts with global climate change. The ENSO phenomenon is a major cause of year-to-year variability in the number of cyclones in the Asia Pacific region (Li, 1987; Nishimori and Yoshino, 1990; Lander, 1994). The numbers are higher during La Niña events, particularly late in the season over southeast Asia (Kelly and Adger, 2000). The 1982–1983 El Niño caused a decline in rainfall and associated impacts over large areas, including parts of Indonesia (Salafsky, 1994, 1998; Glantz, 1996). El Niño events are known to have significant impacts on coastal areas and water resources in southeast Asia through decreased precipitation in El Niño years and increased frequency of typhoons in subsequent La Niña years (Kelly and Adger, 2000).

Sea levels of interior seas in arid and semi-arid Asia have dramatically changed, driven either by climatic or anthropogenic factors. The level of the Caspian Sea lowered by about 4 m from 1930 to 1977; since 1978 it has begun rising (Mikhailov, 1998). The coastline also propagated landward by 20–40 km; 2 Mha of farming land and more than 100 oil wells have been inundated. Many cities in the coastal zone, such as Makhachkala and Kaspisk, are seriously damaged (Svitoch, 1997). The Volga delta propagated 17 km during the period of lowering sea level but has retreated 12–15 km during the period of the rise in sea level (Kasimov, 1997; Tian and Liu, 1999). Caspian Sea level fluctuations are attributed mainly to the Volga water discharge controlled by climate anomalies in its catchment area (Malinin, 1994). The Aral Sea area also reduced, from 60,000 to 28,500 km^2, in the period 1960–1989; the exposed seabed (particularly deltas) now have frequent dust and salt storms, and there are shortages of freshwater (Ellis, 1990; Tian and Liu, 1999).

11.2.4.2. Deltas, Estuarine, and Other Coastal Ecosystems

River-borne sediments have formed at least 10 deltas in the coastal zones of Asia with an area of more than 10,000 km^2 each (Coleman and Wright, 1975). Delta and estuarine ecosystems are sensitive to complex responses to agents associated with climate change (Sanchez-Arcilla and Jimenez, 1997). Low-lying deltas are especially vulnerable to sea-level rise and increasing shoreline wave action (Walker, 1998). A decrease in river water discharge, as projected under some climate change scenarios, could lead to hindrance of delta progradation and increase the risk of irreversible change for the ecosystem in estuarine-deltaic areas (Qian, *et al*., 1993; Shi, 1995). Tidal rivers and estuaries will become more prone to saltwater intrusion as a result of projected sea-level rise (Huang, *et al*., 1982; Li, 1984, 1985; Shi, 1995). Sea-level changes associated with global warming would be exacerbated by tectonic submergence, ground subsidence as a result of groundwater withdrawal, rise of water level created by delta progradation, and eustatic sea-level rise.

Low-lying muddy coastlines associated with large deltas form a significant resource and support large human populations. In China, for example, such low-lying deltas cover about 4,000 km—22% of the total coastline. These muddy coastal ecosystems are basically distributed along large deltas and partly in semi-closed bays (Ren, 1985). Erosion of muddy coastlines in Asia—as documented in China, for example—is triggered largely by sediment starvation resulting from human activities and delta evolution rather than sea-level rise (Ji *et al*., 1993; Chen and Chen, 1998). Beach erosion is widespread in the coastal zone of Asia and has been reported in China, Japan, Indonesia, Sri Lanka, Thailand, Bangladesh, and Malaysia (Xia *et al*., 1993; Sato and Mimura 1997; Teh 1997; Nishioka and Harasawa, 1998; Huq *et al.*, 1999; Middleton, 1999).

Coastal wetlands frequently are associated with deltas, estuaries, lagoons, and sheltered bays. Tidal flats of the muddy coast in Asia constitutes the main part of the coastal wetland (Bird, 1992). Large-scale wetland reclamation in the major deltas has taken place during the past few decades (Lang *et al*., 1998; Liu *et al*., 1998). Lagoons, which are important wetlands, are located across the coastal regions of India, Sri Lanka, Malaysia, Indonesia, China, and Russia. The transitional area between uplift and subsidence belts has favored the formation of lagoons along China's coastline (Li and Wang, 1991). These lagoons tend to be decreasing in area as a result of silting of sediments and plant growing (Zhu, 1991). Sea-level rise and reduction of river-borne sediments will decelerate delta progradation and wetland renewal. The rich biodiversity of wetlands in Asia is seriously threatened by loss of wetlands from sea-level rise (Nicholls *et al*., 1999).

Mangroves are made up of salt-adapted evergreen trees; they are restricted to the intertidal zone along the vast coastlines of tropical countries in Asia and extend landward along tidal rivers. The Sundarbans in Bangladesh and adjacent areas in India, covering about 6,000 km^2, are the largest mangrove forests in the world (Allison, 1998). Depletion of mangrove forests by anthropogenic pressures has become a serious problem (Farnsworth and Ellison, 1997). Approxmately half of mangrove forests in Thailand were reduced by 56% during 1961–1996. In the Philippines, more than 75% of the mangrove forests have been lost in less than 70 years. Destruction of Indonesia's estimated 44,000 km^2 of mangroves has taken place mainly since 1975 (Middleton, 1999; UNEP, 1999). Mangrove forests are highly vulnerable to climate change-induced sea-level rise because it will change the salinity distribution and hence productivity. Large-scale changes in species composition and zonation in mangrove forests also are expected as a result of changes in sedimentation and organic accumulation, the nature of the coastal profile, and species interaction (Aksornkaoe and Paphavasit, 1993).

11.2.4.3. Coral Reefs

Coral reefs play a crucial role in fishery production and in protecting the coastline from wave action and erosion (Ruddle *et al*., 1988; Middleton, 1999). Southeast Asia has almost one-third of the world's mapped coral reefs (Pennisi, 1997); these reefs extend to the northern extreme range in Japan (Nishioka and Harasawa, 1998). Coral reef productivity is a function of their structure, biological recycling, and high retention of nutrients. Reefs in Indonesia and the Philippines are noted for extraordinarily high levels of biodiversity: Each contains at least 2,500 species of fish. Severe coral bleaching can occur as a result of seawater warming and clear skies (resulting in higher incident solar radiation).

Major coral bleaching events have occurred in 1983 (Japan, Indonesia), 1987 (Maldives), 1991 (Thailand, Japan), 1995 (Thailand, Philippines), and 1998 (Maldives, Sri Lanka, India, Indonesia, Thailand, Japan, Malaysia, Philippines, Singapore, Vietnam, Cambodia). As a result of the major 1998 coral bleaching in the south Asia region, many reefs dominated by branching species have been severely damaged, with high mortality of these species. In coastal seas around the Maldives, Sri Lanka, the Andaman Islands of India, and Japan, reef community structure has switched from dominance by fast-growing branching species to monopolization by the more physically rigorous and slow-growing massive corals (Wilkinson, 1998). Deforestation in many island countries of Asia and quarrying of live corals for manufacture of calcium carbonate have led to significant coral decline or severe damage to the entire ecosystem.

Studies show that a moderate rise in sea level around the coast of Thailand would stimulate the growth of coral reef flats and extend corals shoreward. The enhanced growth potential is likely to be restricted by human infrastructure and development along the coast (Chansang, 1993). Asia's coral reefs are undergoing rapid destruction in terms of habitat richness (Cesar *et al.*, 1997; Nie *et al*., 1997; Pennisi, 1998) as a result of several factors, including extreme temperatures and solar irradiance, subaerial exposure, sedimentation, freshwater dilution, contaminants, and diseases (Glynn, 1996). Virtually all of the Philippines' reefs and approximately 83% of Indonesia's reefs are at risk from destructive fishing techniques, reef mining, sedimentation, and marine pollution (Middleton, 1999; UNEP, 1999). The increase in atmospheric CO_2 concentration (resulting in higher $CaCO_3$ concentrations in seawater) and consequent rise in sea surface temperature (SST) is likely to have serious damaging effects on reef accretion and biodiversity.

11.2.4.4. Fisheries and Aquaculture

Asia dominates world aquaculture, producing four-fifths of all farmed fish, shrimp, and shellfish (FAO, 1997). Farming of fish, shrimp, shellfish, and seaweeds has become a vital source of food supply in Asia in recent decades. Fishery products are staples for the Asian population and are embedded in its culture. Fish, an important source of food protein, is critical to food security in many countries of Asia, particularly among poor communities in coastal areas. The annual fish catch and aquaculture production in Asia reached a peak at about 20.7 and 19.1 Mt, respectively, in the year 1998. Japan has the largest distant-waters fishery production. Inland fishery production is dominated by China and India, which have shown increases in recent years as a result of stock enhancement practices.

Fish farming requires land and water—two resources that already are in short supply in many countries in Asia. Nearly half of the land now used for shrimp ponds in Thailand was formerly used for rice paddies; water diversion for shrimp ponds has lowered groundwater levels noticeably in coastal areas of Thailand. In China, concern over the loss of arable land has led to restrictions on any further conversion of farmland to aquaculture ponds. Intensive production systems and large-scale facilities used to raise high-value shrimp, salmon, and other premium species has taken a heavy toll on coastal habitats, with mangrove swamps in southeast Asia being cleared at an alarming rate. Thailand lost more than 15% of its mangrove forests to shrimp ponds from 1987 to 1993 (World Bank, 1996). Destruction of mangroves has left these coastal areas exposed to erosion and flooding, altered natural drainage patterns, and increased salt intrusion.

The fishery resources of Japan, China, and many other countries of Asia are being depleted by overfishing, excessive use of pesticides, industrial pollution, red tide, and even construction of dikes and other coastal structures (Zou and Wu, 1993; Sato and Mimura, 1997). Loss of inshore fish nursery habitats to coastal development, as well as pollution from land-based activities, causes significant change to ecosystems supporting fisheries (see also Chapter 6). Marine productivity is greatly affected by temperature changes that control plankton shift, such as seasonal shifting of sardine in the Sea of Japan and induced during the cyclical occurrence of the ENSO in low latitudes (Chen and Shen, 1999; Piyakarnchana, 1999; Terazaki, 1999). The impact of global warming on fisheries will depend on the complicated food chain, which could be disturbed by sea-level rise, changes in ocean currents, and alteration of mixing layer thickness.

Anomalies in the water temperatures of major oceanic currents (e.g., declines in sardine catch in the Sea of Japan associated with changing patterns of the Kuroshio current in ENSO years) have resulted in low commercial fish catch in recent years (Yoshino, 1998b). The steady wintertime decrease in mean wind speed observed over the Sea of Japan between 1960 and 1990 has accelerated surface temperature increase and stagnated bottom water formation in recent years (Varlamov *et al*., 1997). The rise in SST will shift the southern limit of salmon species further to the north (Seino *et al*., 1998). It is also suggested that the Sea of Japan bottom water will become anoxic within a few hundred years; a decreased oxygen supply will lead to major losses in biological productivity in deep waters (Gamo, 1999). Fish production of certain species may decrease because of the decline of river volume (Zhou, 1991). Increases in marine culture products and declines in marine fishery output are current trends in most south Asian countries that are engaged in commercial fishery activity. It is likely that increased surface runoff and higher nutrient load might lead to potentially beneficial increases in plankton within the coastal zone of boreal Asia. However, increased frequency of El Niño events, which are likely in a warmer atmosphere, could lead to measurable declines in plankton biomass and fish larvae abundance in coastal waters of south and southeast Asia (see also Chapter 6). Such declines in lower levels of the food chain will have negative impacts on fisheries in Asia.

11.2.4.5. Tropical Cyclone and Storm Surges

Asia is close to the warm pool of the west equatorial Pacific Ocean, and tropical cyclones and associated storm surges strongly affect coastal zones of tropical and temperate Asia. Tropical cyclones and storm surges are one of most critical factors affecting loss of human lives in India and Bangladesh (Sato and Mimura, 1997). Approximately 76% of the total loss of human lives from cyclonic storms has occurred in India and Bangladesh (Ali, 1999). Several Asian countries are faced with cyclones and associated storm surges every year, which causes serious economic losses (Ali, 1999; Huang, 1999; Kelly and Adger, 2000).

There is concern that global warming may affect tropical cyclone characteristics, including intensity, because SST plays an important role in determining whether tropical disturbances form and intensify. Several researchers have used modeling techniques to examine the possible effects of global warming on tropical storms (Lighthill *et al.*, 1994; Sugi *et al.*, 1996; Henderson-Sellers and Zhang, 1997; Holland, 1997; Tonkin *et al.*, 1997; Henderson-Sellers *et al.*, 1998; Knutson *et al.*, 1998; Krishnamurti *et al*., 1998; Royer *et al*., 1998). Lighthill *et al*. (1994) conclude that there is no reason to expect any overall change in global tropical cyclone frequencies, although substantial regional changes may occur. Recent studies indicate that the maximum potential intensities of cyclones will possibly undergo a modest increase of as much as 10–20% in a warmer atmosphere (see Chapter 3 and TAR WGI Chapter 9). More recent analyses (Nakagawa *et al.*, 1998; Walsh and Pittock, 1998; Jones *et al*., 1999) support the possibility of an increase in cyclone intensity. Coastal erosion in Asia should increase with sea-level rise, and storm surges could still exacerbate hazards, even if the number and intensities of tropical cyclones do not change (IPCC, 1998; Walsh and Pittock, 1998).

11.2.4.6. Potential Impacts and Coastal Zone Management

As outlined in IPCC (1998), climate-related stresses in coastal areas include loss and salinization of agricultural land resulting from changes in sea level, likely changes in the intensity of tropical cyclones, and the possibility of reduced productivity in coastal and oceanic fisheries. Table 11-9 lists estimates of potential land loss resulting from sea-level rise and the number of people exposed, assuming no adaptation (Mimura *et al.*, 1998; Nicholls and Mimura, 1998). These estimates of potential land loss and populations exposed demonstrate the scale of the issue for the major low-lying regions of coastal Asia. The results are most dramatic in Bangladesh and Vietnam, where 15 million and 17 million people, respectively, could be exposed given a relative change in sea level of 1 m (Brammer, 1993; Haque and Zaman, 1993)—though it should be recognized that a 1-m sea-level rise is at the extreme range of presently available scenarios. Nonetheless, these examples demonstrate the sensitivity of coastal areas to climate change impacts and unsustainable utilization of resources in these areas. The impacts could be exacerbated by continued population growth in low-lying agricultural and urban areas (Nicholls *et al.*, 1999). At the same time, adaptation strategies will alter the nature of the risk and change the socially differentiated nature of the vulnerability of populations living in hazardous regions. Response strategies that are based solely on tackling the physical parameters of risks from sea-level rise and tropical cyclones have been shown in some circumstances to enhance the vulnerability of certain parts of the population—usually those with least ability to influence decisionmaking (Blaikie *et al*., 1994; Hewitt, 1997; Mustafa, 1998; Adger, 1999b).

Human activities, including protection facilities themselves, aggravate the vulnerability of the coastal regions to climate change and sea-level rise. There are complex interrelationships and feedbacks between human driving forces and impacts, on one hand, and climate- and sea level-induced changes and effects on the other (IPCC, 1996). At the interface between ocean and terrestrial resources, coastal ecosystems undergo stress from competing multi-usage demands, while having to retain their functional diversity and resilience in the face of global environmental change (Bower and Turner, 1998). To enhance coastal resilience and facilitate adaptation, integrated management of coastal zones must take into account the multiple resource demand and variety of stakeholders, as well as natural variability, recognizing the importance of the institutional, cultural, and historical context (Klein and Nicholls, 1999).

***Table 11-9**: Potential land loss and population exposed in Asian countries for selected magnitudes of sea-level rise and under no adaptation measures (modified from Nicholls and Mimura, 1998; Mimura et al., 1998).*

Country	**Sea-Level Rise (cm)**	**Potential Land Loss** (km^2)	(%)	**Population Exposed** (millions)	(%)
Bangladesh	45	15,668	10.9	5.5	5.0
	100	29,846	20.7	14.8	13.5
India	100	5,763	0.4	7.1	0.8
Indonesia	60	34,000	1.9	2.0	1.1
Japan	50	1,412	0.4	2.9	2.3
Malaysia	100	7,000	2.1	>0.05	>0.3
Pakistan	20	1,700	0.2	n.a.	n.a.
Vietnam	100	40,000	12.1	17.1	23.1

n.a. = not available.

Integrated coastal zone management (ICZM) is an iterative and evolutionary process for achieving sustainable development by developing and implementing a continuous management capability that can respond to changing conditions, including the effects of climate change (Bijlsma *et al.*, 1996). Essentially, ICZM is a cooperative effort on the part of coastal zone stakeholders that results in a "win-win" outcome. ICZM already has been developed and implemented in some Asian countries for the allocation of environmental, sociocultural, and institutional resources to achieve conservation and sustainable multiple use of the coastal zone (Sato and Mimura, 1997). Since the 1970s, the Philippines has formulated programs and projects on coastal management, covering fishery and mangrove reforestation (Perez *et al*., 1999). Mangrove rehabilitation has been recommended to mitigate climate impacts in coastal zones of Vietnam (Tri *et al*., 1998). Since the 1960s, a groundwater withdrawal/pumping-back system has been carried out to mitigate ground subsidence in Shanghai and Tianjing. Fishing in certain seasons has been banned and the annual quality of fish catch restricted in the coastal zone of China (ESD-CAS, 1994). Sri Lanka conserves coastal tourism resources by using ICZM principles (White *et al*., 1997). Coastal natural conservation parks have been established in Bangladesh, Thailand, China, and other countries (Sato and Mimura, 1997; Allison, 1998). However, land ownership and management responsibility issues in Bangladesh have inhibited coastal zone management. Similarly, privatization and decentralization of storm protection systems in Vietnam have created a vacuum for strategic management and increased the potential impacts of climate variability (Adger, 1999b, 2000).

Given that many potential climate change impacts on coastal zones feature irreversible effects, surprise outcomes, and unpredictable changes, the appropriate policy response should be to maximize flexibility and enhance the resilience and adaptation potential of these areas (Pritchard *et al.*, 1998). By contrast, coastal management in Asia to date more often than not has been dominated by policies that have sought to buffer socioeconomic activities and assets from natural hazards and risks via hard engineering protection (Chua, 1998).

11.2.5. Human Health

11.2.5.1. Thermal Stress and Air Pollution-Related Diseases

A remarkable increase in the number of heatstroke patients and mortality was observed when maximum daily temperatures in Nanjing, China, exceeded 36°C for 17 days during July 1988 (Ando *et al*., 1996). In Japan as well, intense heat in summer is now becoming more common in large cities. The numbers of heatstroke patients are reported to have increased exponentially with temperatures of more than 31°C in Tokyo, Japan, and 35°C in Nanjing, China. Beyond a maximum daily temperature of 36°C, a remarkable increase in the number of heatstroke patients and deaths caused by heatstroke has been observed (Honda *et al.*, 1995; Ando, 1998). Typical hyperthermia occurs during hot days and during physical exercise in the summer (Nylen *et al*., 1997).

Climate change will have a wide range of health impacts all across Asia (see Chapter 9). Although a reduction in health stresses and wintertime deaths is anticipated as a result of less frequent occurrence of extreme cold temperatures in boreal and temperate Asia, an increase in the frequency and duration of severe heat waves and humid conditions during the summer will increase the risk of mortality and morbidity, principally in older age groups and urban poor populations of temperate and tropical Asia (Epstein *et al*., 1995). Heat stress-related chronic health damages also are likely for physiological functions, metabolic processes, and immune systems (Bouchama *et al*., 1991; Ando, 1998).

Adverse health impacts also result from the build-up of high concentrations of air pollutants such as nitrogen dioxide (NO_2), ozone, and air-borne particulates in large urban areas. Combined exposures to higher temperatures and air pollutants appear to be critical risk factors for cerebral infarction and cerebral ischemia during the summer months (Piver *et al.*, 1999). As summarized in Figure 11-12, the heat index (a combination of daily mean temperature and relative humidity) and the concentration of NO_2 are shown to be significant risk factors for heatstroke in males age 65 years and older residing in Tokyo, Japan (Piver *et al*., 1999). The number of heatstroke emergency cases per million residents is found to be greater in males than in females in the same age groups. Global warming also will increase the incidences of some diseases, such as respiratory and cardiovascular diseases, in arid and semi-arid, temperate, and tropical Asia.

11.2.5.2. Vector-Borne Diseases

Health impacts secondary to the impacts of climate change on ecological and social systems should include changes in the occurrence of vector-borne infectious diseases in temperate

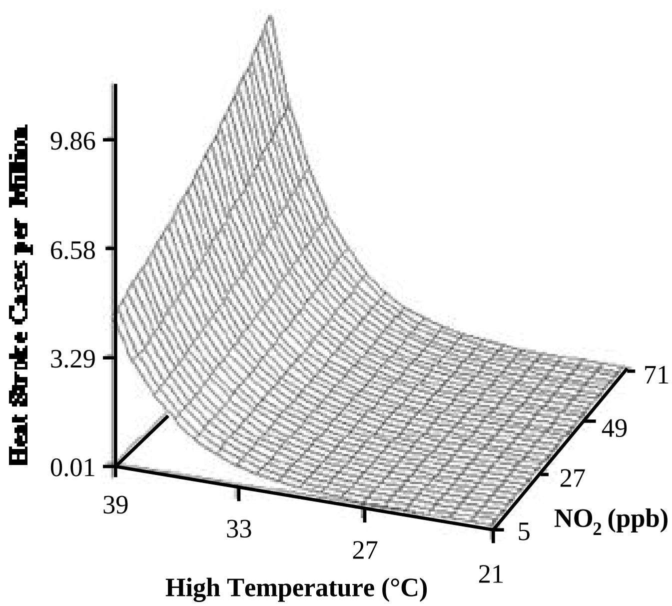

Figure 11-12: Heat stroke morbidity (cases per million; Tokyo, July-August, 1980–1995, males >65 years) (Piver *et al.*, 1999).

and tropical Asia (see Chapter 9). The distribution of diseases such as malaria is influenced by the spread of vectors and the climate dependence of infectious pathogens (Hales *et al.*, 1996; McMichael *et al*., 1996; Epstein *et al*., 1998). In recent years, the resistance of anopheline mosquito to pesticides and of malaria parasites to chloroquine has affected eradication activities (Trigg and Kondrachina, 1998). Malaria still is one of the most important diseases in countries in tropical Asia such as India (Bouma *et al*., 1994; Akhtar and McMichael, 1996; Mukhopadhyay *et al*., 1997), Bangladesh, Sri Lanka (Bouma and Van der Kaay, 1996; Gunawardena *et al.*, 1998), Myanmar, Thailand, Malaysia (Rahman *et al*., 1997), Cambodia, Laos, Vietnam (Hien *et al*., 1997), Indonesia (Fryauff *et al*., 1997), Papua New Guinea (Genton *et al*., 1998), and Yunnan, China (Jiao *et al.*, 1997; Xu and Liu, 1997) as a result of the presence of the mosquito vectors and the lack of effective control.

With a rise in surface temperature and changes in rainfall patterns, the distribution of vectors such as mosquito species may change (Patz and Martens, 1996; Reiter, 1998). Changes in environmental temperature and precipitation could expand vector-borne diseases into temperate and arid Asia. The spread of vector-borne diseases into more northern latitudes may pose a serious threat to human health. Climate change is likely to have principal impacts on epidemics of malaria, dengue, and other vector-borne diseases in Asia (Martens *et al.*, 1999). The epidemic areas of vector-borne diseases in Asia would depend on many demographic and societal factors, as well as environmental hygiene for vector control, available health infrastructure, and medical facilities (see also Chapter 9).

11.2.5.3. Diseases Resulting from Higher UV-B Exposures

Depletion of stratospheric ozone that normally filters out ultraviolet radiation in sunlight in the region from 280 to 320 nm (the UV-B region) has been linked to widespread use of volatile halogenated organic compounds, particularly chlorinated and brominated methanes and chlorofluorocarbons. Some of these compounds also are effective GHGs and therefore contribute to global warming as well. The quantitative relationship between UV-B dose and its physiological effect varies with the wavelength of UV-B exposure (Ilyas *et al.*, 1999). These effects include melanoma and non-melanoma skin cancers, cataracts and other ocular diseases, and dysfunction of the systemic and cutaneous immune systems (Kripke, 1994). The known effects of UV-B on the eye include inflammatory reactions from acute exposure, snow blindness (photo-kerato-conjunctivitis), and long-term damage to the cornea and lens (cataracts) from chronic exposure. It has been demonstrated that damage to melanocytes in human skin initiates the progression of changes leading to melanoma skin cancer (Kripke, 1994). Suppression of the immune response by UV-B radiation involves damage to Langerhans cells and subsequent activation of T-lymphocytes, thus increasing the severity of certain infectious diseases.

The impacts of greater exposure to shorter wavelength UV radiation on human health are cumulative and, for some effects, may have long latencies. Noticeable increases in UV-B radiation over high and mid-latitudes as a result of depletion of stratospheric ozone have occurred in recent decades (Mckenzie *et al*., 1999; WMO, 1999; ACIA, 2000). Climate change could make conditions for the spread of diseases associated with higher UV-B doses more favorable.

11.2.5.4. Other Diseases

The distribution of water-borne infectious diseases is influenced mainly by the hygienic circumstance of water (Epstein, 1992; Echeverria *et al*., 1995; Colwell, 1996; Esrey, 1996). Water-borne diseases—including cholera and the suite of diarrheal diseases caused by organisms such as giardia, salmonella, and cryptosporidium—are common with contamination of drinking water quality in many countries of south Asia (Echeverria *et al*., 1995; Colwell, 1996; Esrey, 1996). Higher SSTs and rich nutrient load in major river deltas would support extended phytoplankton blooms in selected coastal areas of temperate and tropical Asia. These phytoplankton blooms are habitats for the survival and spread of infectious bacterial diseases. The cholera outbreak in Bangladesh during 1994 has been attributed to the presence of extended phytoplankton blooms (Colwell, 1996). The aforementioned water-borne diseases could become more common in many countries of south Asia in a warmer climate.

For preventive actions, impact assessments are necessary on various aspects such as the nutritional situation, drinking water supply, water salinity, and ecosystem damage (Kaye and Novell, 1994; Graczyk and Fried, 1998). Water-borne infectious diseases, natural disaster, environmental migration, nutritional deficiency, and environmental pollution should be major risk factors for human health (Thongkrajai *et al*., 1990; Pazzaglia *et al.*, 1995, Colwell, 1996). The risk factor of diseases also will depend on infrastructure, economic conditions, the hygienic situation, and medical facilities. Risk could be reduced by awareness in the communities that are more vulnerable to instability in the future environment.

In Asia, economic and population growth will expand rapidly during the 21st century in many countries. The rapid increase in population will be accompanied by migration from rural communities to overcrowded large cities (Stephens, 1995). Disasters linked to climate extremes such as floods and droughts also would impact local and regional populations and enforce migration. The huge energy consumption by the expanding population in urban cities would result in degradation of air and water quality, whereas rapid expansion of the economy will bring about improvements in living standards, such as improved environmental sanitation, hygienic practice, and medical treatment facilities. Therefore, better understanding of the interaction among climate change and environmental and health status in communities at regional and local scales is crucial to forge physiological acclimatization and social adaptations in the future.

11.2.6. Human Dimensions

11.2.6.1. Climate Extremes and Migration

The impacts of climate change on Asia will place additional stress on socioeconomic and physical systems. These pressures may induce change in demographic processes. Demographic trends, including the stability and size of populations, will be influenced directly through the impacts of climate change on human health as described in Section 11.2.5 and indirectly through the impacts of climate change on food security and the viability of natural resource-based economic activity. A further demographic response will come about through the risk of extreme events on human settlements. If the incidence and magnitudes of events such as droughts and coastal floods increase, there could be large-scale demographic responses—for example, through migration. Migration in itself is not necessarily a signal of vulnerability to present-day extreme events. Motivations for migration are diverse; much rural-to-urban migration in Asia takes place as a result of increased economic opportunities in megacities (cities with at least 8 million inhabitants). Future increases in the frequency and intensity of severe weather systems as a consequence of climate change can trigger mass migration, however.

The annual rate of growth in migration on a global scale has been greatest in developing countries of south and southeast Asia. For instance, population growth and land scarcity has encouraged the migration of more than 10 million Bangladesh natives to neighboring Indian states during the past 2 decades. This migration has been exacerbated by a series of floods and droughts affecting the livelihoods of landless and poor farmers in this region. Land loss in coastal areas resulting from inundation from sea-level rise as a result of climate change is likely to lead to increased displacement of resident populations. Many south Asian countries increasingly expect the number of internally displaced persons to rise in future.

Immigrant labor often benefits both the donor and the host cities/countries (Connell and Conway, 2000). However, perceptions of regional/national identity, language/cultural differences, and fears of unemployment may contribute to increased hostilities between immigrants and nationals in years to come. Climate change will act in parallel with a complex array of social, cultural, and economic motivations for and impacts of migration (Pebley, 1998; Conway *et al*., 2000; Kates, 2000). Irrespective of resource constraints in developing countries of Asia, they have to better equip themselves through appropriate public education and awareness programs with disaster preparedness measures, including infrastructures for effective resettlement of displaced people as a consequence of weather calamities.

11.2.6.2. Infrastructure Linkages

The urban population in Asia is growing at four to five times the rate of the rural population. At this rate, more than 60% of the people in Asia will be living in towns and cities by 2015. An estimated 80% of the increase will occur in developing countries. The number of megacities in Asia would grow to at least 23 of the world's 36 by the year 2015 (United Nations, 1998). Urbanization is rapid in fast-growing economies of south and southeast Asia, where the average annual urban growth rate is more than 4%. The current pace and scale of change often strains the capacity of local and national governments to provide even the most basic services to urban residents. An estimated 25–40% of urban inhabitants in developing countries today live in impoverished slums and squatter settlements, with little or no access to water, sanitation, or refuse collection (World Bank, 1997).

Basic infrastructure demand in urban corridors is likely to increase dramatically in the future. Already governments in several developing countries of Asia are introducing suites of acts and laws to ensure provision of adequate public services and minimize adverse effects on surrounding communities and ecosystems. For instance, Indonesia introduced the Spatial Use Management Act in 1992 for the identification of environmentally sensitive areas—where development activities would be restricted—and for improved planning for the location and support of activities such as industrial development (Djoekardi, 1995). Developing countries in Asia would soon need to develop new priorities and policies that try to address demands created by the increasing number of people in cities while capitalizing on the benefits of urbanization, such as economic growth and efficient delivery of services. Climate change has the potential to exacerbate basic infrastructure demands of urban inhabitants in many countries of Asia.

11.2.6.3. Industry, Energy, and Transportation

In many cities in the developing countries of Asia, movement of the labor force from dispersed agricultural centers to concentrated industrial sectors has increased urbanization and expansion of the suburban area where industries are located. This situation has caused serious traffic, housing, and sanitary problems. Moreover, a substantial share of industrial growth in developing countries revolves around the transformation of raw materials into industrial products such as steel, paper, and chemicals. Production of industrial chemicals has been shifting from developed countries to developing countries of Asia in recent years. Not only are these processes resource-intensive, in addition, industries such as electricity generation, chemicals and petroleum refining, mining, paper production, and leather tanning tend to produce a disproportionately large amount of hazardous and toxic wastes and already have caused serious air and water pollution. Moreover, because of poor regulatory capacity, developing countries have become targets for dumping of toxic wastes such as polychlorinated biphenyls (PCBs) by multinational companies.

In developing countries of Asia, an increase in paper consumption of more than 80% is expected to occur by 2010. However, a shortfall in the supply of all wood products and especially pulp and paper is likely in the 21st century as a result of declines in natural vegetation productivity. This trend will put immense pressure on unmanaged forests of Asia. Some countries in Asia have resorted to agroforestry and farm woodlots to meet their increasing demand for pulp and paper on a near-term basis. Over the long term, however, anticipated growth in demand for wood products of all types probably will necessitate changes in forest management practices such as greater reliance on industrial plantations. Heat stress to livestock herded in open areas would reduce animal weight gain, dairy and wool production, and feed conversion efficiency in arid and semi-arid Asia (IPCC, 1996). An increase in the frequency of drought and heavy rainfall could result in a decline in tea yield in Sri Lanka (IPCC, 1998). Climate change could have adverse impacts on agroindustries such as food, beverages, tobacco, natural fiber textiles, leather, wood, and rubber.

The manufacturing industry could be affected indirectly through the availability of water, energy supply, and transportation systems throughout Asia. Mining operations, which are required to produce raw materials such as coal (practiced intensively in China and India because of heavy demand), exposes sulfur- and iron-bearing rocks to weathering and erosion that would be aggravated by global warming. Mineral industries discharge large amounts of waste ore known as tailings. Manufacturing industries release effluent to the air and water during production processes. For instance, cement production and foundry operations release particulates; metal industries release SO_2, CO_2, HF, and organic solvents; and chemical plants release particulates, SO_2, and various hydrocarbons. Food processing, pulp and paper industries, brewing, and tanning industries release effluents in the form of contaminated water and sediments. This degradation of the environment may be exacerbated by climate change.

Climate change will adversely affect hydroelectric energy generation in Asia, exacerbating already depleted water resources in several major rivers in Asia. Increased humidity and hence more cloudiness in a warmer atmosphere could inhibit direct solar radiation. Photovoltaic technology, which is used extensively in Indonesia and a few other south Asian countries for remote area electrification programs, could be jeopardized. Changes in wind patterns could affect existing windmill installations. Availability of biomass, particularly fuel wood, depends on forest area and the quantity of rainfall. In areas with excess rainfall, CO_2 enrichment and higher temperatures could increase fuelwood production and supply. Geothermal resources also may be affected by changes in precipitation patterns. For instance, an increase in rainfall could increase recharge of groundwater for most geothermal fields (IPCC, 1996).

In general, no major impacts of climate change on the production and distribution facilities of fossil fuels are likely, other than policies aimed at reducing GHG emissions from burning of fossil fuels. However, offshore exploration, production, and distribution facilities of oil and natural gas would be influenced by sea-level rise and extreme weather events such as cyclonic storms and associated surges that are likely to be exacerbated by climate change. Most power plants and oil refineries in Asia also are located along the coastlines to facilitate transportation and easy access to cooling water supply. Construction of seawalls will be needed to protect these facilities against sea-level rise (Mimura *et al*., 1998).

As reported in IPCC (1996), energy demand for heating, cooling, and agriculture activities can be influenced by climate change. Global warming would increase energy demand for cooling in the tropical Asia region and reduce energy demand for heating in boreal Asia. Asimilar pattern could be observed in temperate Asia, either in summer or winter. For agricultural activities, more energy would be needed for irrigation pumping during warmer weather as the soil becomes drier.

Tourism and outdoor recreational activities are likely to be disrupted in pattern by climate change. Global warming is expected to shorten the skiing season in many areas and affect the feasibility of some ski facilities (IPCC, 1998). Summer recreational activities in coastal recreational areas may be affected with the inundation of beaches. In Malaysia, for example, unprotected resorts located near the coastline would be lost through erosion; others that are not affected by erosion or inundation will cease to operate because of the loss of beaches (Teh, 1997). The increased frequency of forest fires because of drier conditions in Indonesia during the 1997 El Niño resulted in haze that affected the tourism industries of Indonesia, Singapore, and Malaysia (Schweithelm *et al*., 1999). Some wildlife reservation areas that are famous as tourist spots may lose their attraction because of the disappearance of flora and fauna in the changed ecosystems. For example, it has been suggested that the flowering dates of cherry blossoms in Japan and Korea could move 3–4 days earlier if air temperatures during March increase by 1°C (Seino *et al*., 1998). Extreme weather events in highland regions also would threaten rafting, mountain climbing, and other high-altitude tourism.

Transportation systems, including infrastructure and fuel, can be influenced directly and indirectly by climate change. A longer rainy season, melting of ice deposits, and sea-level rise could directly damage infrastructures such as roads, railways, runways, terminals, airports, and harbors, thereby disrupting transportation systems. Climate change would increase the inherent necessity for expansion of infrastructure and alter fuel consumption patterns. In Siberia, for instance, frozen rivers that currently are used as roads would require a shift to water transport or construction of permanent roads with shorter winters. As reported in IPCC (1996), similar impacts could be experienced from permafrost melting.

11.2.6.4. Financial Aspects

The financial services sector typically includes banking, insurance, stock exchanges, and brokerages, as well as financial services firms such as investment banks, advisory services, and asset management, among others. Banking crises, currency speculation, and devaluation have become common in recent years in Asia and now are key policy concerns. Climate change could have serious consequences for this sector because many adaptation and mitigation measures such as crop insurance against floods or droughts are mediated or implemented through this sector. The implications and role of risk management techniques such as derivatives, options, and swaps are some of the new developments in financial services to dampen the impact of disasters on national finances.

There is a growing body of literature on the economic impacts of global warming that takes adaptation into account in estimating the imposed costs of climate change, but these studies fall short of specifically estimating the costs and benefits of adaptation. The basis for estimating adaptation costs is the economic opportunity cost of a product or activity. Estimating this cost requires price and other data from market transactions such as sectoral coverage and assumptions about markets, behaviors, and policy instruments in addition to economic growth path as a function of socioeconomic conditions, resource endowment, and government policies. Multiple baseline choices are critical in the estimation and evaluation of the financial costs, based on accurate reporting of financial flows (see also Chapter 8).

Although global gross domestic product (GDP) has increased by a factor of three since 1960, the number of weather-related disasters has increased four-fold, real economic losses seven-fold, and insured losses 12-fold in the same period (see also Chapter 8). These losses have had some notable regional impacts—particularly in developing countries of Asia, where the impacts of climate change are expected to be greatest in terms of loss of life and effects on investment. Individual large events have shown visible short-term impacts on insurance profitability and pricing and public finance. There is only limited penetration of or access to insurance in developing countries. This situation makes them more vulnerable and will impair their ability to adapt. The property/casualty insurance segment and small specialized or undiversified companies have greater sensitivity. Coping mechanisms and adaptation strategies will depend largely on public or international support. Given finite financial resources and international aid, increased climate-related losses would compete with development efforts.

Adaptation to climate change presents complex challenges to the finance sector. Increasing risk could lead to a greater volume of traditional business, as well as development of new risk and financing products (e.g., catastrophe bonds). However, increased variability of loss events would result in greater actuarial uncertainty. The design of an optimal adaptation program in any country would have to be based on comparison of damages avoided with the costs of adaptation. Other factors, particularly in developing countries with incomplete markets, also enter the decisionmaking process—such as the impacts of policies on different social groups in society, particularly those that are vulnerable; employment generation and opportunities; improved air and water quality; and the impacts of policies on broader concerns such as sustainability.

11.3. Vulnerability and Adaptation Potential

11.3.1. Resilience of Resources, Populations, and Infrastructure

The adaptive capacity of a resource system or a human society depends on the resilience of these systems. Resilience in the face of climate change, as with resilience to present-day hazards such as floods and droughts, therefore depends on the scale, intensity, and rate of change of the climate system, as well as the inherent ability of ecosystems or communities to adjust to new circumstances (Riebsame *et al*., 1995). Resilience is the ability of a system to return to a predisturbed state without incurring any lasting fundamental change. Resilient resource systems recover to some normal range of operation after a perturbation. The processes of short-term adjustment to changes in land productivity and food scarcity in traditional societies of Asian countries are resilient to perturbations. This resilience has been demonstrated in a range of resource systems throughout Asia, including highland agriculture, large-scale irrigated agriculture, and fishery-dependent communities (e.g., Bray, 1986; Bayliss-Smith, 1991; Tang 1992; Grove *et al*., 1998; Ruddle, 1998; Adger, 1999a). Long-term adaptation to climate change requires anticipatory actions, which would require considerable investment of capital, labor, and time hence diversion from scarce available resources, existing services, and infrastructure. Constraints on such resources clearly are more acute in the developing countries of Asia. The three crucial sectors of land resources, water resources, and food productivity are of highest priority for planned adaptation, particularly for the poorer resource-dependent countries.

Adaptation to climate change in Asian countries depends on the real cost of adaptive measures, the existence and engagement of appropriate institutions, access to technology, and biophysical constraints such as land and water resource availability, soil characteristics, genetic diversity for crop breeding (e.g., development of heat-resistant rice cultivars), and topography. Demand for land and water already is increasing to support growing populations, increased agricultural activities, and expanding modern urban infrastructure. Most developing countries in Asia face significant impacts from present-day climatic hazards. Faced with impending floods, the economic insecurity of communities and rural households, lack of timely warnings, ignorance of the severity of danger from flood, and lack of efficient transport systems, some developing countries of Asia often choose not to evacuate homes to avoid climate-related disasters. Such circumstances also act as constraints for the alleviation of poverty and hence reinforce social vulnerability. For many developing countries in Asia, climate change is only one of a host of environmental problems; these countries have to individually and collectively evaluate the tradeoffs between climate change actions and nearer term needs (such as food security, air and water pollution, and energy demand). Adaptation measures designed to anticipate the potential effects of climate change can help to offset many of the negative effects (Burton, 1997). Adaptation measures that ameliorate the impacts of present-day climate variability include sea defenses, institutional adaptations, plant breeding, and adoption of new technologies in agriculture. Many countries in Asia already commit significant resources to ameliorating climate-related hazards (e.g., Golubtsov *et al*., 1996; Nishioka and Harasawa, 1998; Ali, 1999; Huq *et al.*, 1999).

Development and broad application of integrated modeling efforts (those that consider interactions of biophysical and socioeconomic factors) and modeling approaches that are particularly applicable at the regional scale warrant increased attention. For example, mountain systems in Asia are vulnerable with respect to ecological and social systems, for reasons of high heterogeneity. Management of Asia's mountain landscape therefore demands diversified strategies that link ecological and social components for location-specific solutions (Ehrenfeld, 1991; Ramakrishnan, 1992). Inclusion of complex feedbacks between systems may change significantly the current "mean" estimate of impacts.

Sustainable development within Asia's agroecosystems is crucial to provide adequate food security for traditional farming communities in the lowlands and the uplands in developing countries and to ensure *in situ* conservation of crop biodiversity for sustaining high-input modern agriculture itself. However, conserving biodiversity with concerns for higher production from these complex agroecosystems is a challenging task, for which novel development alternatives are required (Ramakrishnan, 1992; Ramakrishnan *et al*., 1996; Swift *et al*., 1996). Traditional societies have always manipulated biodiversity to ensure ecosystem resilience and to cope with uncertainties in the environment, rather than to increase production on a short-term basis. There is increasing evidence now to suggest that we could learn from their traditional ecological knowledge base (Gadgil *et al*., 1993) for coping with uncertainties associated with global change.

The resilience of agricultural practices in the face of climate change depends on the nature and magnitude of region-specific climate change, regional sensitivity, or the threshold and social resilience and adaptive capacity of agricultural communities. Adjustment of planting dates to minimize the effect of temperature increase-induced spikelet sterility can be used to reduce yield instability, for example, by avoiding having the flowering period to coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability may include changing the cropping calendar to take advantage of the wet period and to avoid extreme weather events (e.g., typhoons and storms) during the growing season. Crop varieties that are resistant to lodging (e.g., short rice cultivars) may withstand strong winds during the sensitive stage of crop growth. Acombination of farm-level adaptations and economic adjustments such as increased investment in agriculture infrastructure and reallocation of existing land and water resources would be desired in the agriculture sector. Increasing demand for water by competing sectors may limit the viability of irrigation as a sustainable adaptation to climate change. Expansion of irrigation as a response to climate change will be difficult and costly in many of the countries in Asia even under favorable circumstances. Mounting societal pressures to reduce environmental degradation will likely foster an increase in protective regulatory policies, further complicating adaptations to climate change (Easterling, 1996).

A commonly prescribed adaptation to climate change in the water sector is to enhance characteristics that offer flexibility hence enhancing resilience. Flexibility issues are particularly important with regard to the development of water resources for industry or agriculture. Major projects such as dams actually may limit flexibility if they lose effectiveness as regional hydrological water balances undergo major changes. With likely changes in climate variability, dams and sea defenses built to withstand a 100-year extreme event may not be adequate thus leading to a risk of major catastrophe. If hydrological patterns change markedly and irrigated agriculture is required to relocate in response, prior investments may be lost as existing infrastructures become obsolete, and additional investments will be needed. This necessitates critical scrutiny of a range of available choices that incorporate economic and environmental concerns. The potential for adaptation should not lead to complacency (Rosenzweig and Hillel, 1995). Some adaptive measures may have detrimental impacts of their own.

The issue of natural resource management in Asia has a highly complex set of interconnections between natural and social systems. Natural resource management in largely rural tropical environments must reconcile ecological and social processes that operate at a range of scales, from species up to the landscape level. Studies have shown that ecologically important keystone species often are socially selected by many rural societies (Jodha, 1996). The possibility for species selection for rehabilitating a degraded ecosystem should be based on a value system that the local people understand and appreciate; therefore, their participation in the process of developmental activity is important. Community perceptions of soil and water management can be a powerful agent for sustainable management of natural resources (e.g., in the case of highly fragile and vulnerable Himalayan mountain systems) (Ramakrishnan *et al*., 1994). In other words, natural resource management in tropical Asia must be sensitive to social and even cultural perceptions (Ramakrishnan, 1998), as well as traditional resource management practices.

Major fishery-related environmental issues include the effects of trawling on sea-bottom habitats and the detrimental effects of catches of nontarget species on populations and ecosystems. Fishery resources also are threatened by activities other than commercial fishing. Loss of inshore fish nursery habitats from coastal development and pollution from land-based activities cause significant change to ecosystems that support fisheries. Effective conservation and sustainable management of marine and inland fisheries are needed at the regional level so that living aquatic resources can continue to meet regional and national nutritional needs. Asian economic growth has failed to alleviate poverty for a large share of Asian people to date. Achieving economic and industrial growth in Asia that is sustainable—both ecologically and economically viable over the long term—would require more than just cleaner, more efficient industrial processes; it demands a reorientation toward becoming less material-intensive and attempting to contribute toward protecting our environment and ecosystem.

11.3.2. Regional and Sectoral Strategies

Regions of the Asian continent differ widely in their biophysical characteristics hence in their physical vulnerability to climate change. Different regions also experience highly differentiated social vulnerability. Adaptation strategies therefore will be differentiated across regions and sectors, depending on their vulnerability profiles. In the following subsections, vulnerabilities and related adaptation strategies are discussed for four broad regions of Asia and for selected sectors.

11.3.2.1. Boreal Asia

At present, only areas of sporadic permafrost are used for agriculture. Global warming should play a positive role for agriculture in boreal Asia. The growing season is likely to expand by 1–1.5 months by 2100. The increase in mean monthly air temperatures during the summer will increase active soil temperatures. In addition, winter air temperatures will substantially increase (Sirotenko *et al*., 1997). Shifts in the limit of the permafrost zone to the north, formation of vast areas of perennial ground thawing, and better soil climate will contribute to a northward shift of agriculture boundary. The key step for an agriculture adaptation strategy could be the choice of suitable crops and cultivars. Shifts in sowing date of spring crops will allow more effective use of the soil moisture content formed by snow melting. The dates of spring crop sowing could be moved forward in a crop rotation calendar in southern regions, and farmers could plant a second crop that could even be vegetable with a short growth period (Laverov, 1998). Optimum use of fertilizers and ecologically clean agrotechnologies would be beneficial for agriculture.

Climate change has the potential to exacerbate water resource stresses in some areas but ameliorate them in most parts of boreal Asia. The increase in surface temperatures will have considerable effect on the timing of snowmelt hence the timing of the flow regime (Arnell, 1999). Diversions of water systems would adversely impact fisheries and fishery habitat in the region (Rozengurt, 1991). A decrease in water flow during the dry summer season is likely in some parts of boreal Asia. Extraction of groundwaters from deep aquifers has been proposed as an option, keeping in view the likely surface water quality deterioration during dry periods (Laverov, 1998). It would be necessary to increase the capacity of recycled water supply systems and autonomous water-use systems. However, even with water-saving measures it may be necessary to cut water intake for industry needs during dry periods to meet increasing demand in the future. Bottom-deepening along navigation channels may be required to facilitate the transport of goods and material through rivers.

11.3.2.2. Arid and Semi-Arid Asia

The major impact of climate change in arid and semi-arid Asia is likely to be an acute shortage of water resources associated with significant increases in surface air temperature. Conservation of water used for irrigated agriculture therefore should be given priority attention. With increased evapotranspiration, any adaptation strategy in agriculture should be oriented toward a shift from conventional crops to types of agriculture that are not vulnerable to evapotranspiration (Safriel, 1995). These strategies entail either intensive agriculture in greenhouses—within which rates of evapotranspiration are much reduced—or developing alternatives such as aquaculture that will partly replace agriculture (e.g., fish for human/animal feed, crustaceans for human feed, and unicellular algae for fish/prawn feed, as well as for food additives and medicinal and cosmetic uses). All of these organisms are of high yield; they enjoy solar radiation and often heat, and they do not evaporate or transpire water. Expansion of commercial and artesian fisheries also could help reduce dependence on food productivity. Protection of soils from degradation should be given serious consideration.

Climate change would exacerbate threats to biodiversity resulting from land-use/cover change and population pressure in Asia. Ecosystem services can be impaired by loss of key species in arid and semi-arid Asia (Xiao *et al.,* 1998). Because intraspecies variation in response to environmental stress usually exists in populations subjected to year-to-year climate change, some genotypes in such populations are expected to be more resistant to climate change than others. Such genotypes are more common in peripheral populations than in core populations of species. Although the core population may become extinct because of global warming, resistant types in peripheral populations will survive and can be used to rehabilitate and restore affected ecosystems (Safriel *et al*., 1994; Kark *et al*., 1999). The geographic locations of the peripheral species population usually coincide with climatic transition zones, such as at the edges of drylands or along the transition between different types of drylands. Many countries in the region have more than one dryland type and hence should have peripheral populations—especially in desert and nondesert transitions, which often occur within semi-arid drylands. Identifying regions with concentrations of peripheral populations of species of interest and protecting their habitats from being lost to development therefore can play a role in enhancing planned adaptation for natural and semi-natural ecosystems.

11.3.2.3. Temperate Asia

Projected surface warming and shifts in rainfall in temperate Asia are significant and will induce increases in photorespiration, maintenance respiration, and saturation deficits—causing stomatal closure and decline in productivity (White *et al.*, 1999). An adaptive response in the agriculture sector should be an effort to breed heat-resistant crop varieties by utilizing genetic resources that may be better adapted to warmer and drier conditions. Improvements in farming systems, fertilizer management, and soil conservation form major adaptation strategies (Lou and Lin, 1999). Research is needed to define current limits to heat resistance and the feasibility of manipulating such attributes through modern genetic techniques. Crop architecture and physiology may be genetically altered to adapt to warmer environmental conditions. The genetic resources of seeds maintained in germplasm banks may be screened to find sources of resistance to changing diseases and insects, as well as tolerances to heat and water stress and better compatibility with new agriculture technologies. Genetic manipulation also may help to exploit the potentially beneficial effects of CO_2 enhancement on crop growth and water-use efficiency.

The process of rapid urbanization and industrialization in several Asian megacities has placed enormous stress on urban infrastructure, human well-being, cultural integrity, and socioeconomic arrangements. These urban cities are giant resource sinks and create a large "ecological footprint" on the surrounding countryside. The negative environmental impacts of expanding cities are already large; as they continue to grow and become more prosperous, these impacts are likely to increase. Rising levels of air and water pollution in many of the large cities are considerable. Production and consumption systems that sustain life in cities are largely responsible for many of these changes. As climate changes, the demand for basic infrastructure facilities such as housing, electricity, food supply and distribution, and drinking water supply will increase, and municipalities would have a difficult time managing waste recycling and waste disposal. Development policies that mitigate or avert some of these long-term problems would have to be country-specific and depend heavily on the availability of infrastructure resources, the size of the floating population, and sustainable behavioral changes in society.

Climate change will impinge on a diverse, complex, and dynamic form of climatic hazards such as floods, droughts, sea-level rise, and storm surges in the countries of temperate Asia. Preparation for changes in climate variability should include provision for the possibility of increased flooding, as well as incidences of drought. The present path of development in this region is placing more fixed infrastructures and economic activity within the coastal zone. This trend seems to offer limited scope for adjustments against flooding in the coastal zone resulting from sea-level rise. The likelihood of damage to infrastructure and loss of human life because of unexpected extreme events will rise. A wide range of precautionary measures at the regional and national levels—including awareness, perception, and the acceptability of risk factors among regional communities—are warranted to avert or reduce the impacts of such disasters on economic and social structures. Many current technical and socioeconomic barriers will need to be overcome to prevent risks to human health resulting from increases in disease incidences associated with climate change.

11.3.2.4. Tropical Asia

Agricultural adaptation to climatic variability is an evolving process. Planned interventions through research, extension, or pricing or marketing policies can have inadvertent detrimental impacts for poor farmers. Agricultural productivity in tropical Asia is sensitive not only to temperature increases but also to changes in the nature and characteristics of monsoons. An increase in leaf surface temperatures would have significant effects on crop metabolism and yields, and it may make crops more sensitive to moisture stress (Riha *et al*., 1996). Cropping systems may have to change to include growing suitable cultivars (to counteract compression of crop development), increasing crop intensities (i.e., the number of successive crops produced per unit area per year), or planting different types of crops (Sinha *et al*., 1998). Farmers will have to adapt to changing hydrological regimes by changing crops. For example, farmers in Pakistan may grow more sugarcane if additional water becomes available, and they may grow less rice if water supplies dwindle. The yield ceiling must be raised and the yield gap narrowed while maintaining sustainable production and a friendly environment. Development of new varieties with higher yield potential and stability is complementary to bridging the yield gap. Efficient production of a socially optimal level of agricultural output in this region ultimately may depend on biotechnological applications, but only if these applications prove to be environmentally sustainable.

Groundwater is the main source of freshwater in many parts of tropical Asia, particularly in semi-arid regions. Water resources already are limited in terms of supply and demand in this region. The aquifers in most countries have been depleted by high withdrawal and low recharge rates, and significant drawdown problems exist. Even with increases in precipitation, surface runoff may diminish in some river basins under projected climate change scenarios because of greater evaporation in a warmer atmosphere (higher hydrological elasticity). Increased runoff in some river basins can cause deleterious effects such as greater flooding, waterlogging, and salinity. More than 25% of the irrigated land in the Indus basin already is affected by waterlogging and salinization (Hillel, 1991). Freshwater availability in the coastal regions is likely to undergo substantial changes as a result of a series of chain effects. Improvements in runoff management and irrigation technology (e.g., river runoff control by reservoirs, water transfers, and land conservation practices) will be crucial. Increasing efforts should be directed toward rainwater harvesting and other water-conserving practices to slow the decline in water levels in aquifers. Recycling of wastewater should be encouraged in drought-prone countries in tropical Asia. However, major water development decisions to augment water supplies may have greater relative hydrological, environmental, and social impacts than climate change *per se* in the shorter term. Climate change will affect the benefits to be accrued by future water development projects and therefore should be taken into consideration in the context of water resource policies and planning.

With rapid development of the economy in several countries in tropical Asia during recent decades, the patterns of land use and land cover have been modified significantly; a sequence of transitions and conversions is discernable. As a result of different natural and socioeconomic conditions, the speed and scale of land-use change is very diverse in different parts of Asia. This process has contributed to significant losses in total forest cover; changes in standing biomass and the soil carbon budget; extinction of mammals, birds, and vascular plants; soil degradation; and threats to food security. Excessive human and livestock population pressure in association with inappropriate agricultural extension activities also lend an explanation for widespread land degradation in tropical Asia. Salinization and acidification of soil in low-lying coastal areas would adversely affect cropland in addition to land losses from permanent inundation of deltas from anticipated sea-level rise.

Many of the major rivers originating in mountains and highlands are charged with sediments, depending on the types of land uses in the watersheds (e.g., from forestry and agroforestry to open agriculture). Marginalization of production areas in highlands will continue to increase soil losses, land slips, and slides in the region. It has been suggested that upland micro-watersheds can be hydroecologically sustainable only if good forest cover and dense forests are maintained (Rai, 1999). Under changing climate conditions, the pressure toward small- and large-scale transfers of land for agricultural and urban uses may grow.

Sea-level rise poses the greatest threat and challenge for sustainable adaptation within south and southeast Asia. The sea level already is rising in many locations, primarily as a result of geological processes and anthropogenic manipulations. Projected sea-level rise along the Asian coastlines represents an increase of three to four times over present rates (Chansang, 1993; Midun and Lee, 1995; Mimura and Harasawa, 2000). The potential impacts of accelerated sea-level rise include inundation of low-lying deltas and estuaries, retreat of shorelines, and changes in the water table (Wong, 1992; Sivardhana, 1993). Episodic flooding from high storm surges would penetrate much further inland. Salinization and acidification of soil in low-lying coastal areas will adversely affect agricultural production, in addition to land losses from permanent inundation of deltas from anticipated sea-level rise. The impacts will vary from region to region because of local factors such as land subsidence, susceptibility to coastal erosion or sedimentation, varying tidal ranges, and cyclonicity (Bird, 1993). The Ganges-Brahmaputra in Bangladesh, the Irrawaddy in Myanmar, the Choo Phraya in Thailand, and the Mekong and Song Hong in Vietnam are among the key low-lying river deltas in tropical Asia that are most vulnerable to sea-level rise. Local-level social and institutional adaptations in sensitive regions and development and promotion of risk management can potentially prevent accelerated impacts to these deltas through protection of the ecology of the region from further human interventions so they can sustain themselves at least in a short time horizon.

11.3.3. Institutional and Financial Barriers

As reported in IPCC (1996), the global cost of weather-related disasters to insurers had risen rapidly since 1960 as a result of increased frequency and severity of extreme climate events. The property insurance industry is most likely to be directly affected by climate change because it is already vulnerable to variability in extreme weather events (Dlugolecki *et al.*, 1996). The trend of rapidly growing damage from weather-related disasters has continued. There have been several major climatic hazards in Asia in the late 1990s. There is, however, only very limited penetration of property insurance or agriculture crop insurance in many of the areas that are most affected by recent floods and cyclonic storms. The impacts of flooding are concentrated on the poorest sections of society and people living in marginal areas. There is a need, particularly in Asia, for increased recognition by the financial sector that climate change could affect its future. Climate change can be considered a threat as well as an opportunity for the insurance industry because an increase in risks and perceived risks implies more business opportunities for the sector.

Decisionmaking processes on the choice and capacity of adaptation to the impacts of climate change vary from country to country, depending on its social structure, culture, and economic capacity, as well as the level of environmental disruptions in the Asian region. Institutional inertia, a scarcity of technological adaptation options, and additional economic burdens in developing countries of Asia will be limiting factors for investment in environmental protection and would force people in these countries to face greater risks.

11.4. Synthesis

This chapter discusses the current status of our understanding of likely future changes in climate variables, such as surface temperature, precipitation, soil moisture, extreme events, their potential impacts on natural environment and human society, and possible adaptative options in the Asian region. These factors are delineated on a subregional, national, and sectoral basis. This section attempts to formulate a synthesis of climate change and its implications and consequences for Asia and identify commonality throughout the region, as well as subregional and national differences in terms of climate change and its consequences.

This synthesis also aims to identify the critical climatic threshold, feedbacks, interactions and nonlinearities involved in interactive systems of climate, natural environment, and human society. These analyses will provide a basis for further indepth understanding of the implications of climate change, setting policy-oriented goals to arrest human interventions to the climate system, and planning adaptive responses.

11.4.1. Key Observations and Uncertainties

Asia is characterized by an extreme diversity of natural environment, in longitudinal, latitudinal, and vertical directions. Each subregion and country is supported by natural resources such as water, forests, grasslands/rangelands, and fisheries, which have been utilized by diverse Asian societies in a sustainable manner over the centuries. Promotion of public awareness and participation in region-specific adaptation and mitigation strategies is essential, however, particularly in the developing countries of Asia, to effectively and collectively overcome problems associated with climate change. In general, climate change will impose significant stresses on available natural resources throughout Asia. At the same time, combinations of specific geographical settings and changes in climate will bring about different impacts on different subregions.

Asia has long been affected by natural hazards such as intense rainfall, flooding, droughts, extreme temperatures, snow avalanches, and other impacts of tropical cyclones, monsoons, and ENSO. The security and sustainability of the region is highly dependent on future trends of such extreme events and preparedness for them. However, there remains great uncertainty in projections of likely changes in tropical cyclones, monsoons, and El Niño. It should be noted that the key vulnerabilities related to such natural hazards are still largely qualitative, and there are possibilities of unforeseen surprises in the future.

Many systems are sensitive to natural climate variability in Asia as well as climate change and hence may not be resilient to climate change. These systems include mangroves, lakes, glaciers, deltas, rivers, and ecosystems within the permafrost region. Threshold levels of response are likely to be exceeded by projected climate change. Changes in these systems will occur at different climate thresholds in various regions of Asia. For example, a 0.5°C rise in mean temperature and 10-cm rise in sea level could lead to inundation of 15% (approximately 750 km^2) of the Bangladesh Sundarbans, the largest mangrove ecosystem in Asia. A 45-cm rise in sea level, corresponding to a 2°C rise in mean temperature, is required to introduce changes in the low saline zone of the Sundarbans (Smith *et al*., 1998). Table 11-10 lists selected examples of regions that are sensitive to climate change, based on region- and country-specific studies.

Although many resource systems and populations exhibit high degrees of resilience and adaptive capacity, there is a significant risk that critical thresholds may be breached as a result of climate change, undermining this resilience. The environmental risks in a region could vary significantly for different sectors, depending on the degree of warming. To develop a risk profile for precautionary management of climate change, it is necessary to assess the critical climate threshold for a region for each of the relevant priority sectors, such as water and agriculture. For instance, a small degree of surface warming could be beneficial for agriculture in Russia but may be detrimental in India or Bangladesh. Increased glacier melt in the Himalayas may cause serious floods in Nepal, India, and Bangladesh. The potential environmental risks to water and marine resources in marginal seas of Asia such as the Sea of Japan, Bohai Bay, and the Yellow Sea also will depend on the degree of climate change—which could differ significantly in these regions. For many countries in Asia, there is sparse scientific research on the evaluation of sector-specific critical climatic thresholds. The response of driving forces such as economic growth, population increase, and technological progress in each country or region also should be included in the determination of thresholds for precautionary risk management as an adaptation strategy to climate change.

Table 11-10*: Sensitivity of selected Asian regions to climate change (based on ICRF, 1998; Mirza, 1998; Smith et al., 1998; Mizina et al., 1999).*

Change in Climatic Elements and Sea-Level Rise	**Vulnerable Region**	**Primary Change**	**Impacts**	
			Primary	Secondary
0.5–2°C (10- to 45-cm sea-level rise)	Bangladesh Sundarbans	– Inundation of about 15% (~750 km^2) – Increase in salinity	– Loss of plant species – Loss of wildlife	– Economic loss – Exacerbated insecurity and loss of employment
4°C (+10% rainfall)	Siberian permafrosts	– Reduction in continuous permafrost – Shift in southern limit of Siberian permafrost by ~100–200 km northward	– Change in rock strength – Change in bearing capacity – Change in compressibility of frozen rocks – Thermal erosion	– Effects on construction industries – Effects on mining industry – Effects on agricultural development
>3°C (>+20% rainfall)	Water resources in Kazakhstan	– Change in runoff	– Increase in winter floods – Decrease in summer flows	– Risk to life and property – Summer water stress
~2°C (-5 to 10% rainfall; 45-cm sea-level rise)	Bangladesh lowlands	– About 23–29% increase in extent of inundation	– Change in flood depth category – Change in monsoon rice cropping pattern	– Risk to life and property – Increased health problems – Reduction in rice yield

Rapid demographic transition accompanying significant economic growth is likely in many Asian countries in the 21st century. These trends exacerbate pressures on resource use, the climate system, and the natural environment. Population growth and varying economic and technological conditions in Asia are likely to affect some societies and resources more than changes in climate *per se*. Moreover, socioeconomic and technological developments will interact with many vulnerable sectors. However, predicting population growth rates and future economic conditions is as uncertain an exercise as predicting the future climate. Institutional and legal structures may change and will co-evolve with climatic risks. GHG emission scenarios are especially important, but future emission trends will depend on population growth and prevailing economic and technological conditions. There have been limited studies that simultaneously take into account climate change and other human-induced stresses. For vulnerability and adaptation to be addressed comprehensively, they must be considered in a context of multiple stresses caused by climate change and other anthropogenic activities.

Table 11-11 summarizes the vulnerability of key sectors, from food and fiber through settlements, for subregions of Asia. This summary is derived from a synthesis of available scientific research reviewed in this chapter; it represents a consensus view of the authors. Levels of confidence assigned to vulnerability also are shown in Table 11-11, again based on iterative assessment of the available scientific evidence. Currently available research synthesized in this table reveals a wide range of vulnerability, as well as a wide range of uncertainties in the assessment of these vulnerabilities. Geographical resolution as well as integration and scaling of basic physical and biological responses are the key factors contributing to these uncertainties. The limited database also makes it difficult to aggregate various responses with only a few sample or spot assessments. Nevertheless, some key trends emerge from the synthesis. Aconsistent message is the vulnerability of south and southeast Asia across many sectors, as well as a high degree of confidence about this assertion.

Across virtually all subregions, water resources and natural ecosystems are appraised as highly vulnerable to climate change, although the level of confidence varies for some regions because of lack of data or greater complexity in the resource systems. There may be some minor benefits to boreal Asia, making it more resilient to potential impacts, but natural ecosystems clearly are under threat in this subregion.

11.4.2. Future Needs

The early signs of climate change already observed in some parts of Asia and elsewhere may become more prominent over the period of 1 or 2 decades. If this time is not used appropriately, it may be too late to avoid upheavals and significant human impacts for some nations. Climate change could lead either to cooperation or to conflict over the world's major resources. Integrated planning may be the greatest global challenge, now motivated by the potential for environmental and social transformation caused by climate change.

In the 21st century, Asian countries will have to produce more food and other agricultural commodities under conditions of diminishing per capita arable land and irrigation water resources and expanding biotic as well as abiotic stresses, including climatic constraints. The dual demands for food and ecological security would have to be based on appropriate use of biotechnology, information technology, and ecotechnology. Practical achievements in bringing about the desired paradigm shift in sustainable agriculture will depend on public policy support and political action. Critical areas for intervention would be:

- Improving the availability of seed/planting material of high-yielding varieties
- Developing and promoting the use of hybrids, especially for rainfed agro-ecosystems
- Expanding areas under different crops and commodities, through diversification of agriculture

Table 11-11*: Vulnerability of key sectors to impacts of climate change for select subregions in Asia. Vulnerability scale is as follows: highly vulnerable (-2), moderately vulnerable (-1), slightly or not vulnerable (0), slightly resilient (+1), and most resilient (+2). Confidence levels abbreviated to VH (very high), H (high), M (medium), L (low), and VL (very low).*

Regions	Food and Fiber	Biodiversity	Water Resources	Coastal Ecosystems	Human Health	Settlements
Boreal Asia	+1 / H	-2 / M	+1 / M	+1 / L	-1 / L	0 / M
Arid and Semi-Arid Asia						
– Central Asia	-2 / H	-1 / L	-2 / H	-1 / L	-1 / M	-1 / M
– Tibetan Plateau	0 / L	-2 / M	-1 / L	Not applicable	No information	No information
Temperate Asia	-2 / H	-1 / M	-2 / H	-2 / H	-2 / M	-2 / H
Tropical Asia						
– South Asia	-2 / H	-2 / M	-2 / H	-2 / H	-1 / M	-2 / M
– Southeast Asia	-2 / H	-2 / M	-2 / H	-2 / H	-1 / M	-2 / M

- Improving the productivity of crops, existing plantations, and livestock
- Developing infrastructure for post-harvest management, marketing, and agribusiness
- Small farm mechanisms
- Transfer of technological inputs through assessments and refinements at regular time intervals in consonance with our understanding of climate variability and climate change.

Ensuring food security may remain an unaccomplished dream for many Asian countries unless appropriate strategies are put in place to ensure environmental and ecological protection and conservation of natural resources.

The food security issue is highly dependent on equitable guaranteed access to foods. Equitable access is highly differentiated across populations in the agrarian nations of Asia. This situation is further aggravated by natural disasters such as floods and droughts, which are known to have caused great famines in south Asian countries. Poverty in many south Asian countries seems to be the cause of not only hunger but even lack of shelter, access to clean drinking water, illiteracy, ill health, and other forms of human deprivation. Opportunities for assured and remunerative marketing at microenterprise levels should promote equitable use of available food resources.

In view of present uncertainties over the pace and magnitude of climate change, the most promising policy options are those for which benefits accrue even if no climate change takes place. Such policy actions include the following:

- Breeding of new crop varieties and species (heat- and salt-tolerant crops, low-water-use crops)
- Maintenance of seed banks, liberalization of trade of agricultural commodities, flexibility of commodity support programs, agricultural drought management
- Promotion of efficiency of irrigation and water use and dissemination of conservation management practices
- Trans-national cooperation to promote sustainable water resources management and flood risk management
- Rehabilitation of degraded forests and watersheds (such strategies can enhance biodiversity conservation and provide source of livelihood for many poor forest and upland watershed dwellers)
- Strengthening of biophysical and socioeconomic resources and resource use-related databases for natural and social systems and focused research to further our understanding of the climate-ecosystem-social system interaction. Data and information generated through these activities will be useful not only for designing appropriate mitigation and adaptation measures but also for management planning and decisionmaking.

The climate change issue has presented decisionmakers in Asian countries with a set of formidable complications: a considerable number of uncertainties (which are inherent in the complexity of the problem), the potential for irreversible damages to ecosystems, a very long planning horizon, long time lags between GHG emissions and effects, wide regional variation in causes and effects, the global scope of the problem, and the need to consider multiple GHGs and aerosols. The value of better information about climate change processes and impacts and responses to arrest these risks is likely to be great. A prudent strategy to deal with climate change would be to collectively reduce emission levels of GHGs through a portfolio of actions aimed at mitigation and adaptation measures. The agriculture and forestry sectors in several countries of Asia have a large GHG mitigation potential that should make a significant contribution to this strategy.

The principle of sustainable development must guide all future development strategies in developing and developed countries of Asia. Serious efforts toward promoting innovative research on efficient technology options and creative environmental literacy are needed while Asian countries adapt to new environmental policies and programs. The challenge lies in identifying opportunities that would facilitate sustainable development by making use of existing technologies and developing policies that make climate-sensitive sectors resilient to climate variability. This strategy will require developing countries in Asia to have more access to appropriate technologies, information, and adequate financing. In addition, adaptation will require anticipation and planning; failure to prepare systems for projected change in climate means, variability, and extremes could lead to capital-intensive development of infrastructures or technologies that are ill-suited to future conditions, as well as missed opportunities to lower the cost of adaptation.

References

ACIA, 2000: An assessment of consequences of climate variability and change and the effects of increased UV in the Arctic region. In: *State of the Arctic Environment Report*. Arctic Climate Impact Assessment, Oslo, Norway.

Adger, W.N., 1999a: Evolution of economy and environment: an application to land use in lowland Vietnam. *Ecological Economics*, **31,** 365–379.

Adger, W.N., 1999b: Social vulnerability to climate change and extremes in coastal Vietnam. *World Development*, **27,** 249–269.

Adger, W.N., 2000: Institutional adaptation to environmental risk under the transition in Vietnam. *Annals of the Association of American Geographers*, **90,** 738–758.

Agee, E.M., 1991: Trends in cyclone and anticyclone frequency and comparison with periods of warming and cooling over the Northern Hemisphere. *Journal of Climate*, **4,** 263–267.

Ageta, Y. and T. Kadota, 1992: Prediction of change of mass balance in the Nepal Himalayas and Tibetan Plateau: a case study of air temperature increase for three glaciers. *Annals of Glaciology*, **16,** 89–94.

Aggarwal, P.K. and S.K. Sinha, 1993: Effect of probable increase in carbon dioxide and temperature on productivity of wheat in India. *Journal of Agricultural Meteorology*, **48(5),** 811–814.

Aiba, S. and K. Kitayama, 1999: Species composition, structure and species diversity or rain forests in a matrix of altitude and substraites on Mt. Kinabalu, Borneo. *Plant Ecology*, **140,** 139–157.

Akhtar, R. and A.J. McMichael, 1996: Rainfall and malaria outbreaks in western Rajasthan. *Lancet*, **348,** 1457–1458.

Aksornkaoe, S. and N. Paphavasit, 1993: Effect of sea level rise on the mangrove ecosystem in Thailand. *Malaysian Journal of Tropical Geography*, **24(1–2),** 29–34.

Alfiorov, A.M., V.N. Busarov, G.V. Menzulin, S.A. Pegov, V.S. Savenko, V.A. Smirnova, V.A. Smolina, and P.M. Khomiakov, 1998: *Impact of Environmental and Climatic Global Changes on Russian Economy.* Ministry of Science and Technology of Russian Federation, Moscow, Russia, 102 pp. (in Russian).

Ali, A., 1999: Climate change impacts and adaptation assessment in Bangladesh. *Climate Research, CR Special 6*, **12(2/3),** 109–116.

Ali, S., 1985: *The Fall of a Sparrow.* Oxford University Press, New Delhi, India.

Allison, M.A., 1998: Geological framework and environmental status of the Ganges-Brahmaputra Delta. *Journal of Coastal Research*, **14(3),** 794–825.

Ando, M., 1998: Risk assessment of global warming on human health. *Global Environmental Research,* **2,** 69–78.

Ando, M., K. Tamura, S. Yamamoto, C.K. Liang, Y.P. Wu, J.P. Zhang, Z.C. Mao, M.M Yang, and A.L. Chen, 1996: Outline of health effects of global climate change. *Journal of Epidemiology*, **6,** 141–144.

Anisimov, O.A., 1999: Impact of climate change on heating and air-conditioning. *Meteorology and Hydrology,* **6,** 10–17 (in Russian).

Anisimov, O.A. and F.E. Nelson, 1997: Permafrost zonation and climate change in the Northern Hemisphere: results from transient general circulation models. *Climatic Change*, **35,** 241–258.

Anisimov, O.A. and F.E. Nelson, 1996a: Permafrost distribution in the Northern Hemisphere under scenarios of *Climatic Change*. *Global and Planetary Change*, **14,** 59–72.

Anisimov, O.A. and F.E. Nelson, 1996b: Permafrost and global warming: strategy of adaptation. In: *Adapting to Climate Change: Assessments and Issues* [Smith J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 440–449.

Anokhin, Y.A. and Y.A. Izrael, 2000: Monitoring and assessment of the environment in the Lake Baikal region. *Aquatic Ecosystem Health and Management*, **3,** 199–201.

Arnell, N.W., 1999: Climate change and global water resources. *Global Environmental Change,* **9,** S51–S67.

Azam, J.P., 1996: The impact of floods on the adoption rate of high yielding rice varieties in Bangladesh. *Agricultural Economics,* **13,** 179–189.

Balling, R.C. and S.E. Idso, 1990: Effects of greenhouse warming on maximum summer temperatures. *Agricultural and Forest Meteorology*, **53,** 143–147.

Bandyopadhyay, M., 1993: Impact of rising sea levels along the Indian coastline. In: *Global Warming: Concern for Tomorrow* [Lal, M. (ed.)]. Tata McGraw-Hill Publishing Company Limited, New Delhi, India, pp. 153–66.

Bapat, N.N., 1992: A visit to the 'flamingo city'in the Great Rann of Kutch, Gujarat. *Journal of the Bombay Natural History Society*, **89,** 366–367.

Barber, C.V. and J. Schweithelm, 2000: *Trial by Fire: Forest Fire and Forestry Policy in Indonesia's Era of Crisis and Reform.* World Resource Institute, Forest Frontiers, World Wide Fund for Nature(WWF)-Indonesia, Telapak Indonesia Foundation, 448 pp.

Bardin, M.Y., 1994: Parameters of cyclonicity at 500 mb in the Northern Hemisphere extratropics. In: *Proceedings of XVIII Climate Diagnostic Workshop, Boulder, CO.* National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA, USA, 397 pp.

Bayliss-Smith, T., 1991: Food security and agricultural sustainability in the New Guinea Highlands: vulnerable people, vulnerable places. *IDS Bulletin*, **22(3),** 5–11.

Bhaskaran, B., J.F.B. Mitchell, M. Lal, and J. Lavery, 1995: Climatic response of Indian subcontinent to doubled CO_2 concentration. *International Journal of Climatology*, **15,** 873–892.

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Pérez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: Coastal zones and small islands. In: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 289–324.

Bird, E.C.F., 1993: Sea level rise impacts in Southeast Asia: an overview. *Malaysian Journal of Tropical Geography*, **24(1–2),** 107–110.

Bird, E.C.F., 1992: The impacts of sea level rise on coral reefs and reef islands. In: *Ocean Management in Global Change* [Fabbri, P. (ed.)]. Elsevier, London, United Kingdom and New York, NY, USA, pp. 90–107.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner, 1994: *At Risk: Natural Hazards, People's Vulnerability and Disasters*. Routledge, London, United Kingdom, pp. 57–79.

Boer, G.J., G. Flato, C. Reader, and D. Ramsden, 1999: A transient climate change simulation with greenhouse gas and aerosol forcing: projected climate for the 21st century. *Climate Dynamics*, **16,** 405–425.

Born, K., 1996: Tropospheric warming and changes in weather variability over the Northern Hemisphere for the period 1967–91 using two data sets. *Meteorology and Atmospheric Physics*, **59,** 201–215.

Botch, M.S., K.I. Kobak, T.S. Vinson, and T.P. Kolchugina, 1995: Carbon pools and accumulation in peatlands of the former Soviet Union. *Global Biogeochemical Cycles*, **9,** 37–46.

Bouchama, A., R.S. Parhar, A. El-Yazigi, K. Sheth, and S. Al-Sedairy, 1991: Endotoxemia and release of tumor necrosis factor and interleukin 1 alpha in acute heatstroke. *Journal of Applied Physiology*, **70(6),** 2640–2644.

Bouchard, R.H., 1990: A climatology of very intense typhoons: or where have all the super typhoons gone? In: *1990 Annual Tropical Cyclone Report*. Joint Typhoon Warning Center, Guam, pp. 266–269.

Bouma, M.J. and H.J. Van der Kaay, 1996: The El Niño-Southern Oscillation and the historic malaria epidemics on the Indian subcontinent and Sri Lanka: an early warning system for future epidemics? *Tropical Medecine and International Health,* **1,** 86–96.

Bouma, M.J., H.E. Sondorp, and H.J. Van der Kaay, 1994: Climate change and periodic epidemic malaria. *Lancet*, **343,** 1440.

Bower, B.T. and R.K. Turner, 1998: Characterising and analysing benefits from integrated coastal management. *Ocean and Coastal Management,* **38,** 41–66.

Brammer, H., 1993: Geographical complexities of detailed impacts assessment for the Ganges-Brahmaputra-Meghna delta of Bangladesh. In: *Climate and Sea Level Change: Observations, Projections and Implications* [Warrick, R.A., E.M. Barrow, and T.M.L. Wigley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 246–262.

Bray, F., 1986: *The Rice Economies: Technology and Development in Asian Societies*. Blackwell, Oxford, United Kingdom, 254 pp..

Budyko, M.I. and G.V. Menzhulin, 1996: Climate change impacts on agriculture and global food production: options for adaptive strategies. In: *Adapting to Climate Change: Assessment and Issues* [Smith J., R. Benioa, N. Bhatti, M.I. Budyko, M. Campos, B. Jallow, G. Menzhulin, and F. Rijsberman (eds.). Springer-Verlag, New York, NY, USA, pp. 188–203.

Burton, I., 1997: Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change*, **36,** 185–196.

CAFW, 1998: Comprehensive assessment of the freshwater resources of the world. In: *Assessment of Water Resources and Water Availability in the World* [Shiklomanov, I.A. (ed.)]. World Meterological Organization, Geneva, Switzerland, 88 pp.

Cesar, H., C.G. Lundin, S. Bettencourt, and J. Dixon, 1997: Indonesia coral reefs—an economic analysis of a precious but threatened resource. *Ambio,* **26,** 345–350.

Chakraborty, B. and M. Lal, 1994: Monsoon climate and its change in a doubled CO_2 atmosphere as simulated by CSIRO9 model. *Terrestrial, Atmospheric and Oceanic Sciences*, **5(4),** 515–536.

Chan, J.C.L. and J. Shi, 1996: Long-term trends and interannual variability in tropical cyclone activity over the western North Pacific. *Geophysical Research Letters*, **23,** 2765–2767.

Chandrapala, L. and T.K. Fernando, 1995: Climate variability in Sri Lanka—a study of air temperature, rainfall and thunder activity. In: *Proceedings of the International Symposium on Climate and Life in the Asia-Pacific, University of Brunei, Darussalam, 10–13 April, 1995*.

Chansang, H., 1993: Effect of sea level rise on coral reefs in Thailand. *Malaysian Journal of Tropical Geography*, **24(1–2),** 21–28.

Chaudhari, Q.Z., 1994: Pakistan's summer monsoon rainfall associated with global and regional circulation features and its seasonal prediction. In: *Proceedings of the International Conference on Monsoon Variability and Prediction, Trieste, Italy, May 9–13, 1994*.

Chen, X.Q. and J.Y. Chen, 1998: A study of enclosure depth on the profiles of the Changjiang deltaic coast: on the fundamental problems associated with Bruun Rule and its application. *Acta Geographica Sinica*, **53(4),** 323–331 (in Chinese with English abstract).

Chen, Y.Q. and X.Q. Shen, 1999: Changes in the biomass of the East China Sea ecosystem. In: Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management [Sherman, K. and Q.S. Tang (eds.)]. Blackwell Science, Oxford, United Kingdom, pp. 221–239.

Chua, T.-E., 1998: Lessons learned from practicing integrated coastal management in southeast Asia. *Ambio*, **27,** 599–610.

CIA, 1998: *The World Factbook*. Central Intelligence Agency, Washington, DC, USA. Available online at http://www.odci.gov/cia/publications/factbook/index.html.

Clark, B. and P. Duncan, 1992: Asian wild asses—hemiones and kiangs. In: *Zebra, Asses and Horses: An Action Plan for the Conservation of Wild Equids*. The World Conservation Union (IUCN), Gland, Switzerland, pp. 17–22.

Coleman, J.M. and L.D. Wright, 1975: Modern river deltas: variability of processes and sand bodies. In: *Deltas: Models for Exploration* [Broussard, M.L. (ed.)]. Houston Geological Society, Houston, TX, USA, pp. 99–149.

Collins, M., 1999: The El-Niño Southern Oscillation in the second Hadley Centre coupled model and its response to greenhouse warming. *Journal of Climate*, **13,** 1299–1312.

Colwell, R., 1996: Global climate and infectious disease: the cholera paradigm. *Science*, **274,** 2025–2031.

Connell, J. and D. Conway, 2000: Migration and remittances in island microstates: a comparative perspective on the South Pacific and the Caribbean. *International Journal of Urban and Regional Research*, **24,** 52–78.

Conway, D., K. Bhattarai, and N.R. Shrestha, 2000: Population-environment relations at the forested frontier of Nepal. *Applied Geography*, **20,** 221–242.

Cubasch, U., G.C. Hegerl, and J. Waszkewitz, 1996: Prediction, detection and regional assessment of anthropogenic climate change. *Geophysica*, **32,** 77–96.

Dai, X.S., 1997: Potential effects of climatic variation on geographical distribution of wheat in China. *Quarterly Journal of Applied Meteorology*, **8(1),** 19–25.

Daily, G.C. (ed.) 1997: *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC, USA, 412 pp.

Dixon, R.K, O.N. Krankina, and K.I. Kobak, 1996: Global climate change adaptation: examples from Russian boreal forests. In: *Adapting to Climate Change: Assessments and Issues* [Smith J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 359–373.

Djoekardi, A.D., 1995: Urban land use planning policy in Indonesia. In: *Proceedings of the International Workshop on Policy Measures for Changing Consumption Patterns, Seoul, Republic of Korea, Aug 30–Sep 1, 1995*.

Dlugolecki, A.F., K.M. Clark, F. Knecht, D. McCauley, J.P. Palutikof, and W. Yambi, 1996: Financial services. In: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 536–560.

Dow, K., 1999: The extraordinary and the everyday in explanations on vulnerability to oil spill. *Geographical Review*, **89,** 74–93.

Dyurgerov, M. and M. Meier, 1997: Mass balance of mountain and subpolar glaciers: a new global assessment for 1961–1990. *Arctic and Alpine Research*, **29,** 379–391.

Easterling, W.E., 1996: Adapting North American agriculture to climate change: a review. *Agricultural and Forest Meteorology*, **80,** 1–53.

Echeverria, P., C.W. Hoge, L. Bodhidatta, O. Serichantalergs, A. Dalsgaard, B. Eampokalap, J. Perrault, G. Pazzaglia, P. O'Hanley, and C. English, 1995: Molecular characterization of Vibrio cholerae 0139 isolates from Asia. *American Journal of Tropical Medicine and Hygiene*, **52(2),** 124–127.

Ehrenfeld, D., 1991: The management of biodiversity—a conservation paradox. In: *Ecology, Economics, Ethics: The Broken Circle* [Bormann, F.H. and S.R. Kellert (eds.)]. Yale University Press, New Haven, CT, USA, pp. 26–39.

Ellis, W.S., 1990: The Aral—a Soviet sea lies dying. *National Geographic*, **177(2),** 73–92.

Epstein, P.R., 1992: Cholera and the environment. *Lancet*, **339,** 1167–1168.

Epstein, P.R., A. Haines, and P. Reiter, 1998: Global warming and vector-borne disease. *Lancet*, **351,** 1737–1738.

Epstein, Y., E. Sohar, and Y. Shapiro, 1995: Exceptional heatstroke: a preventable condition. *Israel Journal of Medical Science*, **31,** 454–462.

ESD-CAS, 1994: *Impact of Sea Level Rise on the Deltaic Regions of China and Its Mitigation*. Earth Science Division, Chinese Academy of Sciences, Science Press, Beijing, China, 355 pp. (in Chinese).

Esrey, S.A., 1996: Water, waste, and well being: a multi-country study. *American Journal of Epidemiology*, **143(6),** 608–623.

FAO, 1999a: *Production Yearbook 1999*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 1999b: *The State of Food Insecurity in the World 1999.* Food and Agriculture Organization of the United Nations, Rome, Italy, 32 pp.

FAO, 1997: *The State of World Fisheries and Aquaculture, Yearbook Vol. 84.* Food and Agriculture Organization of the United Nations, Rome, Italy, 57 pp.

FAO, 1996: *World Food Survey—1996*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Farnsworth, E.J. and A.M. Ellison, 1997: The global conservation status of mangroves. *Ambio*, **26(6),** 328–334.

Field, C.B., J.G. Osborn, L.L. Hoffman, J.F. Polsenberg, D.D. Ackerley, J.A. Berry, O. Bjorkman, A. Held, P.A. Matson, and H.A. Mooney, 1998: Mangrove biodiversity and ecosystem function. *Global Ecology and Biogeography Letters*, **7,** 3–14.

Fischer, G., K. Frohber, M. Parry, and C. Rosenzweig, 1996: Impacts of potential climate change on global and regional food production and vulnerability. In: *Climate Change and World Food Security* [Downing, T.E. (ed.)]. Springer-Verlag, Berlin, Germany, pp. 115–159.

Fischer, G., K. Frohber, M. Parry, and C. Rosenzweig, 1995: Climate change and world food supply, demand, and trade. In: *Climate Change and Agriculture: Analysis of Potential International Impacts* [Rosenzweig, C., J.T. Ritchie, J.W. Jones, G.Y. Tsuji, and P. Hildebrand (eds.)]. ASA Special Publication No. 59, American Society of Agronomy, Madison, WI, USA, pp. 341–382.

Fryauff, D.J., E. Gomez-Saladin, Purnomo, I. Sumawinata, M.A. Sutamihardja, S. Tuti, B. Subianto, and T.L. Richie, 1997: Comparative performance of the Parasite F test for detection of plasmodium falciparum in malaria-immune and non-immune populations in Irian Jaya, Indonesia. *Bulletin of the World Health Organization*, **75(6),** 547–552.

Fujimoto, N., T. Fukushima, Y. Inamori, and R. Sudo, 1995: Analytical evaluation of relationship between dominance of cyanobacteria and aquatic environmental factors in Japanese lakes. *Water Environment*, **18,** 901–908 (in Japanese with English abstract).

Fukushima, T., N. Ozaki, H. Kaminishi, H. Harasawa, and K. Matsushige, 2000: Forecasting the changes in lake water quality in response to climate changes, using past relationships between meteorological conditions and water quality. *Hydrological Processes*, **14,** 593–604.

Fushimi, H., 2000a: Influence of decreased snowfall due to warming climate trends on the water quality of Lake Biwa, Japan. In: A Threat to Life: The Impact of Climate Change on Japan's Biodiversity [Domoto, A., K. Iwatsuki, T. Kawamichi, and J. McNeely (eds.)]. Tsukiji-Shokan Publishing Company, Tokyo, Japan; The World Conservation Union (IUCN), Gland, Swizerland; and IUCN, Cambridge, United Kingdom, pp. 35–37.

Fushimi, H., 2000b: Recent changes in glacial phenomena in the Nepalese Himalayas. In: A Threat to Life: The Impact of Climate Change on Japan's Biodiversity [Domoto, A., K. Iwatsuki, T. Kawamichi, and J. McNeely (eds.)]. Tsukiji-Shokan Publishing Company, Tokyo, Japan; The World Conservation Union (IUCN), Gland, Swizerland; and IUCN, Cambridge, United Kingdom, pp. 42–45.

Gadgil, M., F. Berkes, and C. Folke, 1993: Indigineous knowledge for biodiversity conservation. *Ambio*, **22,** 151–156.

Gadgil, S., 1995: Climate change and agriculture—an Indian perspective. *Current Science*, **69(8),** 649–659.

Gamo, T., 1999: Global warming may have slowed down the deep conveyer belt of a marginal sea of the northwestern Pacific: Japan Sea. *Geophysical Research Letters*, **26(20),** 3137–3140.

Garagulia, L.S. and E.D. Ershov (eds.), 2000: *Geocryological Hazards, Vol. 1 of the Series Natural Hazards of Russia.* Publishing House Kruk, Moscow, Russia, 315 pp. (in Russian).

Genton, B., F. Al-Yaman, M. Ginny, J. Taraika, and M.P. Alpers, 1998: Relation of anthropometry to malaria morbidity and immunity in Papua New Guinean children. *American Journal of Clinical Nutrition*, **68(3),** 734–741.

Giorgi, F. and R. Francisco, 2000: Evaluating uncertainties in the prediction of regional climate. *Geophysical Research Letters*, **27(9),** 1295–1298.

Glantz, M.H., 1996: *Currents of Change: El Niño's Impact on Climate and Society*. Cambridge University Press, Cambridge, United Kingdom, 194 pp.

Glynn, P.W., 1996: Coral reef bleaching: facts, hypotheses and implications. *Global Change Biology*, **2,** 495–509.

Golubtsov, V.V., V.I. Lee, and I.I. Scotselyas, 1996: Vulnerability assessment of the water resources of Kazakhstan to anthropogenic climate change and the structure of adaptation measures. *Water Resource Development*, **12,** 193–208.

Graczyk, T.K. and B. Fried, 1998: Echiostomiasis: a common but forgotten food-borne disease. *American Journal of Tropical Medicine and Hygiene*, **58(4),** 501–504.

Green, J.B., 1990: *IUCN Directory of South Asian Protected Areas*. The World Conservation Union (IUCN), Gland, Switzerland.

Grove, R.H., V. Damodaran, and S. Sangwan, 1998: *Nature and the Orient: the Environmental History of South and Southeast Asia*. Oxford University Press, Oxford, United Kingdom.

Gruza, G. and E. Rankova, 1997: Indicators of Climate Change for the Russian Federation. In: *Proceedings of Workshop on Indices and Indicators for Climate Extremes, Session on Regional Extremes and Indicators Russia/China, Ashville, North Carolina, June 3–6, 1997*, pp. 1–20.

Gruza, G.V., L.K. Kletschenko, and L.N. Aristova, 1999: On relationships between climatic anomalies over the territory of Russia and ENSO event. *Meteorology and Hydrology*, **5,** 26–45 (in Russian).

Gruza, G.V., E. Rankova, M. Bardin, L. Korvkina, E. Rocheva, E. Semenjuk, and T. Platova, 1997: Modern state of the global climate system. In: *Global Changes of Environment and Climate: Collection of Selected Scientific Papers* [Laverov, N.P. (ed.)]. Russian Academy of Sciences, The Federal Research Program of Russia, Moscow, Russia, pp. 194–216.

Gunawardena, D.M., A.R. Wickremasinghe, L. Muthuwatta, S. Weerasingha, J. Rajakaruna, T. Senanayaka, P.K. Kotta, N. Attanayake, R. Carter, and K.N. Mendis, 1998: Malaria risk factor in an endemic region of Sri Lanka, and the impact and cost implications of risk factor-based interventions. *American Journal of Tropical Medicine and Hygiene*, **58(5),** 533–542.

Hales, S., P. Weinstein, and A. Woodward, 1996: Dengue fever in the south Pacific: driven by El Niño-Southern Oscillation? *Lancet*, **348,** 1664–1665.

Halsey, L.A., D.H. Vitt, and S.C. Zoltai, 1995: Disequilibrium response of permafrost in boreal continental western Canada to climate change. *Climatic Change*, **30(1),** 57–73.

Hanaki, K., K. Takara, T. Hanazato, H. Hirakuchi, and H. Kayanne, 1998: Impacts on hydrology/water resources and water environment. In: *Global Warming: The Potential Impact on Japan* [Nishioka, S. and H. Harasawa (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 131–163.

Hansen, J.E., M. Sato, A. Lacis, R. Ruedy, I. Tegen, and E. Matthews, 1998: Climate forcings in the industrial era. *Proceedings of the National Academy of Sciences*, **95,** 12753–12758.

Haque, C.E. and M.Q. Zaman, 1993: Human responses to riverine hazards in Bangladesh: a proposal for sustainable floodplain development. *World Development*, **21,** 93–107.

Hassell, D. and R. Jones, 1999: *Simulating Climatic Change of the Southern Asian Monsoon Using a Nested Regional Climate Model.* Technical Note No. 8, Hadley Centre, Bracknell, Berks, United Kingdom, 16 pp.

Hazell, P.B.R., 1985: Sources of increased variability in world cereal production since the 1960s. *Journal of Agricultural Economics*, **36,** 145–159.

Henderson-Sellers, A. and H. Zhang, 1997: *Tropical Cyclones and global Climate Change. Report from the WMO/CAS/TMRP Committee on Climate Change Assessment*. Project TC-2, World Meteorological Organization, Geneva, Switzerland, 47 pp.

Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S.-L. Shieh, P. Webster, and K. McGuffie, 1998: Tropical cyclones and global climate change: a post-IPCC assessment. *Bulletin of the American Meteorological Society*, **79,** 19–38.

Hewitt, K., 1997: *Regions of Risk: A Geographical Introduction to Disasters*. Addison-Wesley Longman, Essex, United Kingdom, 389 pp.

Hien, T.T., N.V. Vinh Chau, N.N. Vinh, N.T. Hung, M.Q. Phung, L.M. Toan, P.P. Mai, N.T. Dung, D.T. Hoai Tam, and K. Arnold, 1997: Management of multiple drug-resistant malaria in Viet Nam. *Annals of the Academy of Medicine Singapore*, **26(5),** 659–663.

Hillel, D., 1991: *Out of the Earth: Civilization and the Life of the Soil*. University of California Press, Berkeley, CA, USA, 321 pp.

Hirakuchi, H. and F. Giorgi, 1995: Multi-year present day and $2xCO_2$ simulations of monsoon climate over eastern Asia and Japan with a regional climate model nested in a general circulation model. *Journal of Geophysical Research*, **100,** 21105–21126.

Holland, G.J., 1997: The maximum potential intensity of tropical cyclones. *Journal of Atmospheric Science*, **54,** 2519–2541.

Honda, Y., M. Ono, A. Sasaki, and I. Uchiyama, 1995: Relationship between daily maximum temperature and mortality in Kyusyu. *Japanese Journal of Public Health*, **42,** 260–268 (in Japanese with English abstract).

Horie, T., M.J. Kropff, H.G. Centeno, H. Nakagawa, J. Nakano, H.Y. Kim, and M. Ohnishi, 1995a: Effect of anticipated change in global environment on rice yields in Japan. In: Climate Change and Rice [Peng, S., K.T. Ingram, H. Neue, and L.H. Ziska (eds.)]. Springer-Verlag, Berlin, Germany, pp. 291–302.

Horie, T., H. Nakagawa, H.G. Centeno, and M.J. Kropff, 1995b: The rice crop simulation model SIMRIW and its testing. In: *Modeling the Impact of Climate Change on Rice Production in Asia* [Matthews, R.B., D. Bachelet, M.J. Kropff, and H.H. Van Laar (eds.)]. International Rice Research Institute (Philippines) and CAB International, Wallingford, Oxon, United Kingdom, pp. 51–66.

Huang, Z.G., 1999: *Sea Level Changes in Guangdong and Its Impacts and Strategies*. Guangdong Science and Technology Press, Guangzhou, China, 386 pp. (in Chinese).

Huang, Z.G., P.R. Li, and Z.Y. Zhang, 1982: *Zhujiang Delta: Formation, Development and Evolution*. Popular Science Press, Guangzhou, China, 274 pp. (in Chinese).

Huq, S., Z. Karim, M. Asaduzzaman, and F. Mahtab (eds.), 1999: *Vulnerability and Adaptation to Climate Change in Bangladesh*. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, 147 pp.

ICRF, 1998: *Second National Communication*. Interagency Commission of the Russian Federation on Climate Change Problems, Roshydromet, Moscow, Russia, 67 pp.

ICRF, 1995: *First National Communication.* Interagency Commission of the Russian Federation on Climate Change Problems, Roshydromet, Moscow, Russia, 61 pp.

Iglesias, A., L. Erda, and C. Rosenzweig, 1996. Climate change in Asia: a review of the vulnerability and adaptation of crop production. *Water, Air, and Soil Pollution*, **92,** 13–27.

Ilyas, M., A. Pandy, and S.I.S. Hassan, 1999: UV-B radiation at Penang. *Atmospheric Research*, **51,** 141–152.

Inoue, S. and K. Yokoyama, 1998: Estimation of snowfall, maximum snow depth and snow cover condition in Japan under global climate change. *Snow and Ice*, **60,** 367–378 (in Japanese with English abstract).

IPCC, 2000: *Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change* [Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Raihi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

IPCC, 1998: *The Regional Impacts of Climate Change: An Assessment of Vulnerability. Special Report of IPCC Working Group II* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 517 pp.

IPCC, 1996: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 878 pp.

IPCC, 1995: *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emissions Scenarios* [Houghton, J.T., J. Bruce, B.A. Callander, E. Haites, N. Harris, H. Lee, K. Maskell, and L.G. Meira Filho (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 339 pp.

Islam, N. (ed.), 1995: *Population and Food in Early 21st Century: Meeting Future Food Demand of an Increasing Population*. International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Ives, J.D. and B. Messerli, 1989: The Himalayan Dilemma: Reconciling Development and Conservation. Routledge, London, United Kingdom, 336 pp.

Izrael, Y., Y. Anokhin, and A.D. Eliseev, 1997a: Adaptation of water management to climate change. In: *Global Changes of Environment and Climate: Collection of Selected Scientific Papers* [Laverov, N.P. (eds.)]. The Federal Research Program of Russia, Russian Academy of Sciences, Moscow, Russia, pp. 373–392.

Izrael, Y., Y. Anokin, and A.D. Eliseev, 1997b: *Final Report of the Russian Country Study on Climate Problem, Russian Federal Service for Hydrometeorology and Environmental Monitoring, Vol. 3, Task 3: Vulnerability and Adaptation Assessments*. Roshydromet, Moscow, Russia, 105 pp.

Izrael, Y., A.V. Pavlov, and Y. Anokhin, 1999: Analysis of modern and predicted climate and permafrost changes in cold regions of Russia. *Meteorology and Hydrology*, **3,** 18–27 (in Russian).

Japan Meteorological Agency, 1999: *Extreme Weather Report '99.* Printing Bureau, Ministry of Finance, Tokyo, Japan, 341 pp. (in Japanese).

Jarupongsakul, T., 1999: Implications of sea level rise and coastal zone management in the upper Gulf of Thailand. In: *Proceedings of the IPCC Regional Experts Meeting, National Institute of Environmental Studies, Tsukuba, Japan, 21–23 June, 1999*.

Ji, Z.X., Z.X. Jiang, and J.W. Zhu, 1993: Impacts of sea level rise on coastal erosion in the Changjiang Delta Northern Jiangsu coastal plain. *Acta Geographica Sinica*, **48(6),** 516–526 (in Chinese with English abstract).

Jiao, X., G.Y. Liu, C.O. Shan, X. Zhao, X.W. Li, I. Gathmann, and C. Royce, 1997: Phase II trial in China of new, rapidly acting and effective oral anti-malarial CGP56697, for the treatment of plasmodium falciparum malaria. *Southeast Asian Journal of Tropical Medicine and Public Health*, **28(3),** 476–481.

Jodha, N.S., 1996: Property rights and development. In: *Rights to Nature* [Hanna, S.S., C. Folke, and K.-G. Maler (eds.)]. Island Press, Washington, DC, USA, pp. 205–220.

Jones, R.G., J.M. Murphy, and M. Noguer, 1995: Simulation of climate change over Europe using a nested regional climate model, part I: assessment of control climate, including sensitivity to location of lateral boundaries. *Quarterly Journal of Royal Meteorological Society*, **121,** 1413–1449.

Jones, R.N., K.J. Hennessy, C.M. Page, A.B. Pittock, R. Suppiah, K.J.E. Walsh, and P.H. Whetton, 1999: *An Analysis on the Effects of the Kyoto Protocol on Pacific Island Countries, Part Two: Regional Climate Change Scenarios and Risk Assessment Methods*. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Atmospheric Research Report to the South Pacific Regional Environment Programme, Aspendale, Australia, 69 pp. (plus executive summary).

Kane, S., J. Reilly, and J. Tobey, 1991: *Climate Change: Economic Implication for World Agriculture*. AER-No. 647, U.S. Department of Agriculture, Economic Research Service, Washington, DC, USA, 21 pp.

Kark, S., U. Alkon, E. Randi, and U.N. Safriel, 1999: Conservation priorities for chukar partridge in Israel based on genetic diversity across an ecological gradient. *Conservation Biology*, **13,** 542–552.

Karl, T.R., R.W. Knight, and N. Plummer, 1995: Trends in high frequency climate variability in the twentieth century. *Nature*, **377,** 217–220.

Karl, T.R., G. Kukla, V.N. Razuvayev, M.J. Changery, K.G. Quayle, R.R. Heim, D.R. Easterling, and C.B. Fu, 1991: A new perspective on global warming: asymmetric increases of day and night temperatures. *Geophysical Research Letters*, **18,** 2253–2256.

Kasimov, N.S., 1997: *Geo-ecological Changes Under the Caspian Sea Level Fluctuation*. Moscow University Press, Moscow, Russia, 205 pp. (in Russian).

Kates, R.W., 2000: Cautionary tales: adaptation and the global poor. *Climatic Change*, **45,** 5–17.

Kattenberg, A., F. Giorgi, H. Grassl, G.A.Meehl, J.F.B.Mitchell, R.J. Stouffer, T. Tokioka, A.J.Weaver, and T.M.L.Wigley, 1996: Climate models—projections of future climate. In: *Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 285–357.

Katti, M. and T. Price, 1996: Effects of climate on palearctic warblers over wintering in India. *Journal of the Bombay Natural History Society*, **93,** 411–427.

Kaye, K. and M. Novell, 1994: Health practices and indices of a poor urban population in Indonesia, part E: immunization, nutrition, and incidence of diarrhea. *Asia Pacific Journal of Public Health*, **7(4),** 224–227.

Kelly, P.M. and W.N. Adger, 2000: Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change*, **47,** 325–352.

Kelly, P.M., D.A. Campbell, P.P. Micklin, and J.R. Tarrant, 1983: Large scale water transfers in the USSR. *GeoJournal*, **7(3),** 201–214.

Khuldorj, M., M. Badarch, T. Tsetsegee, N. Oyun-erdene, and Chuluuntsetseg, 1998: *The Mongolian Action Programme for 21st Century*. Ulaanbaatar, Mongolia.

Kitayama, K., 1996: Climate of the summit region of Mount Kinabalu (Borneo) in 1992 and El Niño year. *Mountain Research and Development*, **16(1),** 65–75.

Kitayama, K. and D. Mueller-Dombois, 1995: Biological invasion on an oceanic island mountain: do alien plant species have wider ecological ranges than native species? *Journal of Vegetation Science*, **6,** 667–674.

Kitoh, A., S. Yukimoto, A. Noda, and T. Motoi, 1997: Simulated changes in the Asian summer monsoon at times of increased atmospheric CO_2. *Journal of the Meteorological Society of Japan*, **75,** 1019–1031.

Klein, R.J.T. and R.J. Nicholls, 1999: Assessment of coastal vulnerability to climate change. *Ambio*, **28(2),** 182–187.

Knutson, T.R. and S. Manabe, 1998: Model assessment of decadal variability and trends in the tropical Pacific Ocean. *Journal of Climate*, **11,** 2273–2296.

Knutson, T.R., R.E. Tuleya, and Y. Kurihara, 1998: Simulated increase of hurricane intensities in a CO_2-warmed climate. *Science*, **279,** 1018–1020.

Kothyari, U.C. and V.P. Singh, 1996: Rainfall and temperature trends in India. *Hydrological Processes*, **10,** 357–372.

Krankina, O.N., R.K. Dixon, A.P. Kirilenko, and K.I. Kobak, 1997: Global climate change adaptation: examples from Russian boreal forests. *Climatic Change*, **36(1–2),** 197–215.

Kripalani, R.H., S.R. Inamdar, and N.A. Sontakke, 1996: Rainfall variability over Bangladesh and Nepal: comparison and connection with features over India. *International Journal of Climatology*, **16,** 689–703.

Kripke, M.L., 1994: Ultraviolet radiation and immunology: something new under the sun. *Cancer Research*, **54,** 6102–6105.

Krishnamurti, T.N., R. Correa-Torres, M. Latif, and G. Daughenbaugh, 1998: The impact of current and possibly future SST anomalies on the frequency of Atlantic hurricanes. *Tellus*, **50A,** 186–210.

Kropff, M.J., R.B. Matthews, H.H. Van Laar, and H.F.M. Ten Berge, 1995: The rice model ORYZA1 and its testing. In: *Modeling the Impact of Climate Change on Rice Production in Asia* [Matthews, R.B., D. Bachelet, M.J. Kropff, and H.H. Van Laar (eds.)]. International Rice Research Institute (Philippines) and CAB International, Wallingford, Oxon, United Kingdom, pp. 27–50.

Kuzmin, M.I., D. Williams, and T. Kavai, 1997: Baikal drilling project: long-range climate reconstructions. In: *Global Changes of Environment and Climate: Collection of Selected Scientific Papers* [Laverov, N.P. (ed.)]. The Federal Research Program of Russia, Russian Academy of Sciences, Moscow, Russia, pp. 255–281.

Lal, M. and H. Harasawa, 2000: Comparison of the present-day climate simulation over Asia in selected coupled atmosphere-ocean global climate models. *Journal of the Meteorological Society of Japan*, **78(6),** 871–879.

Lal, M. and H. Harasawa, 2001: Future climate change scenarios for Asia as inferred from selected coupled atmosphere-ocean global climate models. *Journal of the Meteorological Society of Japan*, **79(1),** 219–227.

Lal, M., G.A. Meehl, and J.M. Arblaster, 2000: Simulation of Indian summer monsoon rainfall and its intraseasonal variability. *Regional Environmental Change*, **1(3/4),** 163–179.

Lal, M., G. Srinivasan, and U. Cubasch, 1996: Implications of global warming on the diurnal temperature cycle of the Indian subcontinent. *Current Science*, **71(10),** 746–752.

Lal, M., U. Cubasch, R. Voss, and J. Waszkewitz, 1995a: Effect of transient increases in greenhouse gases and sulphate aerosols on monsoon climate. *Current Science*, **69(9),** 752–763.

Lal, M., L. Bengtsson, U. Cubash, M. Esch, and U. Schlese, 1995b: Synoptic scale disturbances of Indian summer monsoon as simulated in a high resolution climate model. *Climate Research*, **5,** 243–258.

Lal, M., U. Cubasch, J. Perlwitz, and J. Waszkewitz, 1997: Simulation of the Indian monsoon climatology in ECHAM3 climate model: sensitivity to horizontal resolution. *International Journal of Climatology*, **17,** 1–12.

Lal, M., P.H. Whetton, A.B. Pittock, and B. Chakraborty, 1998a: Simulation of present-day climate over the Indian subcontinent by general circulation models. *Terrestrial, Atmospheric and Oceanic Sciences*, **9(1),** 69–96.

Lal, M., P.H. Whetton, A.B. Pittock, and B. Chakraborty, 1998b:The greenhouse gas-induced climate change over the Indian subcontinent as projected by general circulation model experiments. *Terrestrial, Atmospheric and Oceanic Sciences*, **9,** 673–690.

Lal, M., B. Bhaskaran, and S.K. Singh, 1998c: Indian summer monsoon variability as simulated by regional climate model nested in a global climate model. *Chinese Journal of Atmospheric Science*, **22(1),** 93–102.

Lal, M., K.K. Singh, L.S. Rathore, G. Srinivasan, and S.A. Saseendran, 1998d: Vulnerability of rice and wheat yields in north-west India to future changes in climate. *Agricultural and Forest Meteorology*, **89,** 101–114.

Lander, M., 1994: An exploratory analysis of the relationship between tropical storm formation in the western north Pacific and ENSO. *Monthly Weather Review*, **122,** 636–651.

Lander, M.A. and C.P. Guard, 1998: A look at global tropical cyclone activity during 1995: contrasting high Atlantic activity with low activity in other basins. *Monthly Weather Review*, **126,** 1163–1173.

Lang, H.Q., P. Lin, and J.J. Lu, 1998: *Conservation and Research of Wetlands in China*. East China Normal University Press, Shanghai, China, 420 pp. (in Chinese with English abstract).

Laverov, N.P. (ed.), 1998: *Global Changes of Environment and Climate: Collection of Selected Scientific Papers*. The Federal Research Program of Russia, Russian Academy of Sciences, Moscow, Russia, 433 pp.

Leggett, J., W.J. Pepper, and R.J. Swart, 1992: Emissions Scenarios for IPCC: an update. In: *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment* [Houghton, J.T., B.A. Callander, and S.K. Varney (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 69–95.

Lelyakin, A.L., A.O. Kokorin, and I.M. Nazarov, 1997: Vulnerability of Russian forests to climate changes, model estimation of CO_2, fluxes. *Climate Change*, **36(1–2),** 123–133.

Li, C.X., 1987: A study of the influence of El Niño upon typhoon action over the western Pacific. *Acta Meteorologica Sinica*, **45,** 229–236.

Li, C.X., 1985: *Luanhe Fan-Delta Depositional Systems*. Geological Publishing House, Beijing, China, 156 pp.

Li, C.X., 1984: Sedimentary processes in the Yangtze Delta since late Pleistocene. *Collected Oceanic Works*, **7(2),** 116–126.

Li, C.X. and P. Wang, 1991: Stratigraphy of the Late Quaternary barrier-lagoon depositional systems along the coast of China. *Sedimentary Geology*, **72,** 189–200.

Li, Z., R. Yang, D. Liu, Q. Fan, and L. Wang, 1991: Research on the relationship between migration of birds of prey and climate in the seaboard of eastern China. *Forest Research*, **4,** 10–14.

Lighthill, J., G.J. Holland, W.M. Gray, C. Landsea, K. Emanuel, G. Craig, J. Evans, Y. Kunihara, and C.P. Guard, 1994: Global climate change and tropical cyclones. *Bulletin of the American Meteorological Society*, **75,** 2147–2157.

Liu, Y.F., M.K. Han, L. Wu, and N. Mimura, 1998: Recent evolution of outlets in Zhujiang River Delta and the prospect for land reclamation. *Acta Geographica Sinica*, **53,** 492–499 (in Chinese with English abstract).

Lou, Q. and E. Lin, 1999: Agricultural vulnerability and adaptation in developing countries: the Asia Pacific region. *Climatic Change*, **43,** 729–743.

Mackenzie, F.T., L.M. Ver, and A. Lerman, 1998: Coupled biogeochemical cycles of carbon, nitrogen, phosphorous and sulfur in the land-ocean-atmosphere system. In: *Asian Change in the Context of Global Climate Change* [Galloway, J.N. and J.M. Melillo (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 42–100.

Makarov, M.V., 1999: Influence of ultraviolet-radiation on growth of the dominant macroalgae of the Barents Sea. *Chemosphere Global Change Science: Climate Change effect on Northern Terrestrial and Freshwater Ecosystems*, **1(4),** 461–469.

Malinin, V.N., 1994: *Problems of the Prediction in Caspian Sea Level Changes*. SANKTPress, St. Petersburg, Russia, 159 pp. (in Russian).

Martens, P., R.S. Kovats, S. Nijhof, P. de Vries, M.T.J. Livermore, D.J. Bradley, J. Cox, and A.J. McMichael, 1999: Climate change and future populations at risk of malaria. *Global Environmental Change*, **9,** S89–S107.

Masuzawa, T., 2000: How will communities of alpine plants be affected by global warming? In: *A Threat to Life: The Impact of Climate Change on Japan's Biodiversity* [Domoto, A., K. Iwatsuki, T. Kawamichi, and J. McNeely (eds.)]. Tsukiji-Shokan Publishing Company, Tokyo, Japan; The World Conservation Union (IUCN), Gland, Swizerland; and IUCN, Cambridge, United Kingdom, pp. 46–51.

Masuzawa, T., 1997: *The Ecology of Alpine Plants*. Tokyo University Press, Tokyo, Japan, 220 pp. (in Japanese).

Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift, 1997: Agricultural intensification and ecosystem properties. *Science*, **277,** 504–509.

Matsui, T. and T. Horie, 1992: Effects of elevated CO_2 and high temperature on growth and yield of rice, part 2: sensitive period and pollen germination rate in high temperature sterility of rice spikelets at flowering. *Japan Journal of Crop Science*, **61,** 148–149.

Matthews, R.B., T. Horie, M.J. Kropff, D. Bachelet, H.G. Centeno, J.C. Shin, S. Mohandass, S. Singh, Z. Defeng, and H.L. Moon, 1995a: A regional evaluation of the effect of future climate change on rice production in Asia. In: *Modeling the Impact of Climate Change on Rice Production in Asia* [Matthews, R.B., M.J. Kropff, D. Bachelet, and H.H. Van Laar (eds.)]. International Rice Research Institute (Philippines) and CAB International, Wallingford, Oxon, United Kingdom, pp. 95–139.

Matthews, R.B., M.J. Kropff, D. Bachelet, and H.H. Van Laar, 1995b: *Modeling the Impact of Climate Change on Rice Production in Asia*. International Rice Research Institute (Philippines) and CAB International, Wallingford, Oxon, United Kingdom, 289 pp.

McKenzie, R.L., B. Connor, and G. Bodeker, 1999: Increased summertime UV radiation in New Zealand in response to ozone loss. *Science*, **285,** 1709–1711.

McMichael, A.J., A. Haines, R. Slooff, and S. Kovats (eds.), 1996: *Climate Change and Human Health*. WHO/EHG/96.7, an assessment prepared by a Task Group on behalf of the World Health Organization, the World Meteorological Organization, and the United Nations Environment Programme, Geneva, Switzerland, 297 pp.

Meehl, G.A. and W.M. Washington, 1996: El Niño-like climate change in a model with increased atmospheric CO_2 concentrations. *Nature*, **382,** 56–60.

Meehl, G.A. and W.M. Washington, 1993: South Asian summer monsoon variability in a model with doubled atmospheric carbon dioxide concentration. *Science*, **260,** 1101–1104.

Melillo, J.M., I.C. Printice, G.D. Farquhar, E.D. Schuze, and O.E. Sala, 1996: Terrestrial biotic responses to environmental change and feedbacks to climate. In: *Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 444–516.

Middleton, N., 1999: *The Global Casino: An Introduction to Environmental Issues*. 2nd. ed., Arnold, London, United Kingdom, 370 pp.

Midun, Z. and S.C. Lee, 1995: Implications of a greenhouse gas induced sea level rise: a national assessment for Malaysia. *Journal of Coastal Research*, **14,** 96–115.

Mikhailov, V.N., 1998: *The Volga River-Mouth area: Hydrological-Morphological Processes, Regime of Contaminants and Influence of the Caspian Sea Level Changes*. Geos Press, Moscow, Russia, 278 pp. (in Russian).

Mimura, N. and H. Harasawa, 2000: *Data Book of Sea-Level Rise 2000*. Centre for Global Environmetal Research, National Institute for Enviromental Studies, Environmetal Agency of Japan, Ibaraki, Japan, 280 pp.

Mimura, N., J. Tsutsui, T. Ichinose, H. Kato, and K. Sakaki, 1998: Impacts on infrastructure and socio-economic system. In: *Global Warming: The Potential Impact on Japan* [Nishioka, S. and H. Harasawa (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 165–201.

Mirza, M.Q., 1998: *Modeling the Effects of Climate Change on Flooding in Bangladesh*. Diss. International Global Change Institute (IGCI), University of Waikato, Hamilton, New Zealand, 279 pp.

Mirza, M.Q. and A. Dixit, 1997: Climate change and water management in the GBM Basins. *Water Nepal*, **5,** 71–100.

Mirza, M.Q. and N.J. Ericksen, 1996: Impact of water control projects on fisheries resources in Bangladesh. *Enviornmental Management*, **20(4),** 527–539.

Mitchell, J.F.B., T.C. Johns, J.M. Gregory, and S.F.B. Tett, 1995: Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature*, **376,** 501–504.

Mizina, S.V., J. Smith, E. Gossen, K. Spiecker, and S. Witowski, 1999: An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. *Mitigation and Adaptation Strategies for Global Change*, **4,** 25–41.

Mukhopadhyay, A.K., P. Karmakar, A.K. Hati, and P. Dey, 1997: Recent epidemiological status of malaria in Calcutta Municipal Corporation area, West Bengal. *Indian Journal of Malariol*, **34(4),** 188–196.

Munasinghe, M., 2000: Development, equity and sustainabillity (DES) in the context of climate change. In: Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999 [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 69–90.

Mustafa, D., 1998: Structural causes of vulnerability to flood hazard in Pakistan. *Economic Geography*, **74(3),** 289–305.

Nakagawa, A., J. Nagasawa, and S. Inoue, 1997: Projection of global warming impacts using world rice and wheat supply and demand model. *Quarterly Journal of National Research Institute of Agricultural Economy*, **36,** 37–50 (in Japanese).

Nakagawa, S., M. Sugi, T. Motoi, and S. Yukimoto, 1998: Climate change projections. In: *Global Warming: The Potential Impact on Japan* [Nishioka, S. and H. Harasawa (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 1–33.

Nakicenovic, N., N. Victor, and T. Morita, 1998: Emissions scenarios database and review of scenarios. *Mitigations and Adaptation Strategies for Global Change*, **3,** 95–120.

Naylor, R, W. Falcon, and E. Zavaleta, 1997: Variability and growth in grain yields, 1950–94: does the record point to greater instability? *Population and Development Review*, **23(1),** 41–61.

NBAP, 2000: *National Biodiversity Action Plan*. Draft plan, His Majesty's Government of Nepal, Nepal.

Nelson, F.E. and O.A. Anisimov, 1993: Permafrost zonation in Russia under anthropogenic climatic change. *Permafrost Periglacial Processes*, **4(2),** 137–148.

Neumann, C.J., 1993: *Global Overview, Global Guide to Tropical Cyclone Forecasting*. WMO/TC No. 560, Report No. TCP-31, World Meteorological Organization, Geneva, Switzerland, Chapter 1, pp. 1–43.

Nicholls, R.J., 1995: Coastal megacities and climate change. *GeoJournal*, **37,** 369–379.

Nicholls, R.J. and N. Mimura, 1998: Regional issues raised by sea level rise and their policy implications. *Climate Research*, **11,** 5–18.

Nicholls, R.J., F.M.J. Hoozemans, and M. Marchand, 1999: Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, **9,** S69–S87.

Nie, B.F., T.G. Chen, and M.T. Lein, 1997: *The Relationship Between Reef Coral and Environmental Changes of Nasha Islands and Adjacent Regions*. China Science Press, Beijing, China, 101 pp. (in Chinese with English abstract).

Nishimori, M. and M. Yoshino, 1990: The relationship between ENSO events and the generation, development and movement of typhoons. *Geographic Review of Japan*, **63A-8,** 530–540 (in Japanese).

Nishioka, S. and H. Harasawa (eds.) 1998: *Global Warming: The Potential Impact on Japan*. Springer-Verlag, Tokyo, Japan, 244 pp.

Nylen, E.S., A. Al-Arifi, K.L. Becker, R.H. Snider Jr., and A. Alzeer, 1997: Effect of classic heatstroke on serum procalcitonin. *Critical Care Medicine*, **25(8),** 1362–1365.

OEPP, 1996: *Report on Environmental Conditions of the Year 1994*. Office of Environmental Policy and Planning, Ministry of Science, Technology and Energy, Bangkok, Thailand, 307 pp. (in Thai).

Omasa, K., K. Kai, H. Toda, Z. Uchijima, and M. Yoshino (eds.), 1996: *Climate Change and Plants in East Asia*. Springer-Verlag, Tokyo, Japan, 215 pp.

Ostby, F.P., 1993: The changing nature of tornado climatology. In: *Proceedings of the 17th Conference on Severe Local Storms, October 4–8, 1993, St. Louis, Missouri*, pp. 1–5.

Patterson, D.T., J.K. Westbrook, R.J.V. Joyce, P.D. Lingren, and J. Rogasik, 1999: Weeds, insects and diseases. *Climatic Change*, *43,* 711–727.

Patz, J.A. and W.J.M. Martens, 1996: Climate impacts on vector-borne disease transmission: global and site-specific. *Journal of Epidemiology*, **6,** S145–S148.

Pazzaglia, G., P. O'Hanley, and C. English, 1995: Molecular characterization of Vibro cholera 0139 isolates from Asia. *American Journal of Tropical Medicine and Hygiene*, **52(5),** 124–127.

Pebley, A.R., 1998: Demography and the environment. *Demography*, **35,** 377–389.

Pender, M., 1995: Recent retreat of the terminus of Rika Samba Glacier, Hidden Valley, Nepal. In: *Himalayan Climate Expedition: Final Report* [Wake, C.P. (ed.)]. Glacier Research Group, University of New Hampshire, pp. 32–39.

Pennisi, E., 1998: New threat seen from carbon dioxide. *Science*, **279,** 989–990.

Pennisi, E., 1997: Brighter prospects for the world's coral reefs? *Science*, **277,** 491–493.

Perez, R.T., L.A. Amodore, and R.B. Feir, 1999: Climate change impacts and responses in the Philippines coastal sector. *Climate Research, CR Special 6*, **12,** 97–107.

Pilifosova, O., I. Eserkepova, and S. Dolgih, 1997: Regional climate change scenarios under global warming in Kazakhstan. *Climatic Change*, **36,** 23–40.

Pilifosova, O., I. Eserkepova, and S. Mizina, 1996: Vulnerability and adaptation assessment for Kazakhstan. In: *Vulnerability and Adaptation to Climate Change—Interim Results from a U. S. Country Study Program* [Smith, J.B., S. Huq, S. Lenhart, L.J. Mata, I. Nemesova, and S. Toure (eds.)]. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 161–181.

Ping, C.-L., 1996: Carbon storage in the Kuparuk River Basin. In: *Proceedings of the Arctic System Science/Land-Atmosphere-Ice Interactions Science Workshop, Seattle, Washington*.

Piver, W.T., M. Ando, F. Ye, and C.T. Portier, 1999: Temperature and air pollution as risk factors for heat stroke in Tokyo, July–August, 1980–1995. *Environmental Health Perspective*, **107(11),** 911–916.

Piyakarnchana, T., 1999: Change state and health of the Gulf of Thailand large marine ecosystem. In: *Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management* [Sherman K. and Tang Q.S. (eds.)]. Blackwell, Oxford, United Kingdom, pp. 240–250.

Popov, Y.M. and T.J. Rice, 1997: Economic and ecological problems of the Aral Sea region during transition to a market economy. *Ecology and Hydrometeorology*, **2,** 24–36.

Portmann, R.W., S. Solomon, J. Fishman, J.R. Olson, J.T. Kiehl, and B. Briegleb, 1997: Radiative forcing of the earth's climate system due to tropical ozone production. *Journal of Geophysical Research*, **102(D8),** 9409–9417.

Primavera, H., 1998: Mangroves as nurseries: shrimp populations in mangrove and non-mangrove habitats. *Estuarine, Coastal and Shelf Science*, **46,** 457–464.

Pritchard, L., J. Colding, F. Berkes, U. Svedin, and C. Folke, 1998: *The Problem of Fit Between Ecosystems and Institutions*. Working Paper No. 2, International Human Dimension Programme, Bonn, Germany. Available online at http://www.uni-bonne.de/ihdp/wp02mam.htm.

Qian, Y.Y., Q.C. Ye, and W.H. Zhou, 1993: *Water Discharge and Suspended Load Changes and Channel Evolution of Huanghe River*. China Building Material Industry Press, Beijing, China, 230 pp. (in Chinese).

Rahman, W.A., A. Che'Rus, and A.H. Ahmad, 1997: Malaria and Anopheles mosquitoes in Malaysia. *Southeast Asian Journal of Tropical Medicine and Public Health*, **28(3),** 599–605.

Rai, S.C., 1999: Land use change and hydrology of a Himalayan watershed. In: *Abstract Book of the 1999 IGES Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Shonan Village, Japan, 24–26 June*, 200 pp.

Ramakrishnan, P.S., 1998: Sustainable development, climate change, and the tropical rain forest landscape. *Climatic Change*, **39,** 583–600.

Ramakrishnan, P.S., 1992: *Shifting Agriculture and Sustainable Development: An Interdisciplinary Study from North-Eastern India*. United nations Educational, Scientific, and Cultural Organization and the Man and the Biosphere Program (UNESCO-MAB) Series, Parthenon Publications, Carnforth, Lancaster, United Kingdom, 424 pp. (republished by Oxford University Press, New Delhi, India, 1993).

Ramakrishnan, P.S., A.N. Purohit, K.G. Saxena, and K.S. Rao, 1994: *Himalayan Environment and Sustainable Development*. Diamond Jubilee Publication, Indian National Science Academy, New Delhi, India, 84 pp.

Ramakrishnan, P.S., A.K. Das, and K.G. Saxena (eds.), 1996: *Conserving Biodiversity for Sustainable Development.* Indian National Science Academy, New Delhi, India, 246 pp.

Rankova, E., 1998: Climate change during the 20th century for the Russian Federation. In: *Abstract Book of the 7th International Meeting on Statistical Climatology, Whistler, British Columbia, Canada, May 25–29*. Abstract 102, p. 98.

Rao, G.D. and S.K. Sinha, 1994: Impact of climate change on simulated wheat production in India. In: *Implications of Climate Change for international agriculture: Crop Modelling Study* [Rosenzweig, C. and I. Iglesias (eds.)]. U.S. Environmental Protection Agency, EPA230-B-94-003, Washington, DC, USA, pp. 1–10.

Reiter, P., 1998: Global warming and vector-borne disease in temperate regions and at high altitude. *Lancet*, **351,** 839–840.

Ren, G., 1998: Temperature changes of the 20th century over Horqin region, Northeast China. *Scientia Meteorologica Sinica*, **18(4),** 373–380.

Ren, G. and W. Zhou, 1994: A preliminary study on temperature change since 1905 over Liaodong peninsula, Northeast China. *Acta Meteorologica Sinica*, **52(4),** 493–498.

Ren, G., H. Wu, and Z. Chen, 2000: Spatial pattern of precipitation change trend of the last 46 years over China. *Journal of Applied Meteorology*, **11(3),** 322–330.

Ren, M.E., 1985: *Modern Sedimentation in Coastal and Nearshore Zone of China*. China Ocean Press, Beijing, China and Springer-Verlag, Berlin and Heidelberg, Germany; New York, NY, USA; and Tokyo, Japan, 464 pp.

Rice, C.G., 1998: Habitat, population dynamics and conservation of Nilgiri tahr (Hemitragus hylocrius). *Biological Conservation*, **44,** 137–156.

Riebsame, W.E., K.M. Strzepek, J.L. Wescoat Jr., G.L. Gaile, J. Jacobs, R. Leichenko, C. Magadza, R. Perrit, H. Phien, B.J. Urbiztondo, P. Restrepo, W.R. Rose, M. Saleh, C. Tucci, L.H. Ti, and D. Yates, 1995: Complex river basins. In: *As Climate Changes, International Impacts and Implications* [Strzepek, K.M. and J.B. Smith (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 57–91.

Riha, S.J., D.S. Wilks, and P. Simons, 1996: Impact of temperature and precipitation variability on crop model predictions. *Climatic Change*, **32,** 293–331.

Robock, A., K.Y. Vinnikov, G. Srinivasan, J.K. Entin, S.E. Hollinger, N.A. Speranskaya, S. Liu, and A. Namkhai, 2000: The global soil moisture data bank. *Bulletin of the American Meteorological Society*, **81,** 1281–1299.

Roeckner, E., L. Bengtsson, J. Feitcher, J. Lelieveld, and H. Rodhe, 1999: Transient climate change with a coupled atmosphere-ocean GCM, including the tropospheric sulphur cycle. *Journal of Climate*, **12,** 3004–3032.

Rosenzweig, C. and D. Hillel, 1998: *Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture*. Oxford University Press, Oxford, United Kingdom, 324 pp.

Rosenzweig, C. and D. Hillel, 1995: Potential impacts of climate change on agriculture and food supply. *Consequences*, **1(2),** 23–32.

Rosenzweig, C. and M.L. Parry, 1993: Potential impacts of climate change on world food supply. In: *Agricultural Dimensions of Global Climate Change* [Keiser, H.M. and T.E. Drennen (eds.)]. St. Lucie Press, Delray Beach, FL, USA, pp. 87–116.

Rounsevell, M.D.A., S.P. Evans, and P. Bullick, 1999: Climate change and agricultural soils—impacts and adaptation. *Climatic Change*, **43,** 683–709.

Royer, J.-F., F. Chauvin, B. Timbal, P. Araspin, and D. Grimal, 1998: A GCM study of the impact of greenhouse gas increase on the frequency of occurrence of tropical cyclones. *Climatic Change*, **38,** 307–343.

Rozengurt, M.A., 1991: Strategy and ecological and societal results of extensive resources development in the south of the U.S.S.R. In: *Proceedings of the Soviet Union in the Year 2010*. USAIA and Georgetown University, Washington, DC, USA.

Ruddle, K., 1998: Traditional community-based coastal marine fisheries management in Vietnam. *Ocean and Coastal Management*, **40,** 1–22.

Ruddle, K., W.B. Morgan, and J.R. Pfafflin, 1988: *The Coastal Zone: Man's Response to Change*. Harwood Academic Publishers, Chur, Switzerland, 555 pp.

Rupakumar, K. and S.D. Patil, 1996: Long-term variations of rainfall and surface air temperature over Sri Lanka. In: *Climate Variability and Agriculture* [Abrol, Y.P., S. Gadgil, and G.B. Pant (eds.)]. Narosa Publishing House, New Delhi, India, pp. 135–152.

Rupakumar, K., K. Krishna Kumar and G.B. Pant, 1994: Diurnal asymmetry of surface temperature trends over India. *Geophysical Research Letters*, **21,** 677–680.

Safriel, U.N., 1995: The role of ecology in desert development. *Journal of Arid Land Studies*, **55,** 351–354.

Safriel, U.N., 1993: Climate change and the Israeli biota: little is known but much can be done. In: *Regional Implications of Future Climate Change* [Graber, M., A. Cohen, and M. Magaritz (eds.)]. The Israeli Academy of Sciences and Humanities, Jerusalem, Israel, pp. 252–260.

Safriel, U.N., S. Volis, and S. Kark, 1994: Core and peripheral populations and global climate change. *Israel Journal of Plant Sciences*, **42,** 331–345.

Salafsky, N., 1998: Drought in the rainforest, part II: an update based on the 1994 ENSO event. *Climatic Change*, **39,** 601–603.

Salafsky, N., 1994: Drought in the rainforest: effects of the 1991 El Niño-Southern Oscillation event on a rural economy in West Kalimantan, Indonesia. *Climatic Change*, **27,** 373–396.

Sanchez-Arcilla, A. and J.A. Jimenez, 1997: Physical impacts of climatic change on deltaic coastal systems: I: an approach. *Climatic Change*, **35,** 71–93.

Sankaran, R., A.R. Rahmani, and U. Ganguli-Lachungpa, 1992: The distribution and status of the lesse florican Sypheotides indica in the Indian subcontinent. *Journal of the Bombay Natural History Society*, **89,** 156–179.

Sato, Y. and N. Mimura, 1997: Environmental problems and current management issues in the coastal zones of south and southeast Asian developing countries. *Journal of Global Environmental Engineering*, **3,** 163–181.

Schulze, E.D., 1994: Flux control at the ecosystem level. *Trends in Ecology and Evolution*, **10,** 40–43.

Schweithelm, J., T. Jessup, and D. Glover, 1999: Conclusion and policy recommendation. In: *Indonesia's Fires and Haze: the Cost of Catastrophe* [Glover, D. and T. Jessup (eds.)]. Institute of Southeast Asia, Singapore, and International Development Research Centre, Ottawa, Ontario, Canada, pp. 130–153.

Seino, H., M. Amano, and K. Sasaki, 1998: Impacts on agriculture, forestry and fishery. In: *Global Warming: The Potential Impact on Japan* [Nishioka, S. and H. Harasawa (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 101–124.

Serebryanny, L.R. and A.G. Khropov, 1997: Natural zones of north of Russia during a climatic holocene optimum. *Russian Academy of Science Report*, **357(6),** 826–827 (in Russian).

Sharma, K.P., 1997: *Impact of Land-Use and Climatic Changes on Hydrology of the Himalayan Basin: A Case Study of the Kosi Basin*. Diss. University of New Hampshire, Durham, NH, USA, 247 pp.

Sharma, K.P., 1993: Role of meltwater in major river systems of Nepal. In: *International Symposium on Snow and Glacier Hydrology* [Young, G.J. (ed.)]. International Association of Scientific Hydrology, Kathmandu, Nepal, pp. 113–122.

Shi, Y.F., 1995: Exacerbating coastal hazards and defensive countermeasures in China. In: *Geological Hazards and Environmental Studies of Chinese Offshore Areas* [Liu, S.Q. and M.S. Liang (eds.)]. Qindao Ocean University Press, Qindao, China, pp. 1–17.

Shiklomanov, I. (ed.), 2001: *World Water Resources at the Beginning of the 21st Century*. International Hydrological Series of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 711 pp.

Singh, P., 1998: Effect of global warming on the streamflow of high-altitude Spiti River. In: *Ecohydrology of High Mountain Areas* [Chalise, S.R., A. Herrmann, N.R. Khanal, H. Lang, L. Molnar, and A.P. Pokhrel (ed.)]. International Centre for Integrated Mountain Development, Kathmandu, Nepal, pp. 103–114.

Singh, N. and N.A. Sontakke, 2001: Natural and anthropogenic environmental changes of the Indo-Gangetic Plains, India. *Climatic Change*, (communicated).

Sinha, S.K., 1997: Global change scenario—current and future with reference to land cover change and sustainable agriculture. *Current Science*, **72(11),** 846–854.

Sinha, S.K., M. Rai, and G.B. Singh, 1998: *Decline in Productivity in Punjab and Haryana: A Myth or Reality?* Indian Council of Agricultural Research (ICAR) Publication, New Delhi, India, 89 pp.

Sirotenko, O.D., H.V. Abashina, and V.N. Pavlova, 1997: Sensitivity of the Russian agriculture to changes in climate, CO_2, and tropospheric ozone concentrations and soil fertility. *Climatic Change*, **36(1–2),** 217–232.

Sivardhana, R., 1993: Methodology of assessing the economic impacts of sea level rise with reference to Ban Don Bay, Thailand. *Malaysian Journal of Tropical Geography*, **24(1–2),** 35–40.

Skole, D.L., W.A. Salas, and C. Silapathong, 1998: Interannual variation in the terrestrial carbon cycle: significance of Asian tropical forest conversions to imbalance in the global carbon budget. In: *Asian Change in the Context of Global Climate Change* [Galloway, J.N. and J.M. Melillo (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 162–186.

Smit, B., I. Burton, R.J.T. Klein, and J. Wandel, 2000: An anatomy of adaptation to climate change and variability. *Climatic Change*, **45,** 223–251.

Smith, J.B., A. Rahman, S. Haq, M.Q. Mirza, 1998: *Considering Adaptation to Climate Change in the Sustainable Development of Bangladesh*. World Bank Report, World Bank, Washington, DC, USA, 103 pp.

Smith, J.B., N. Bhatti, G. Menzhulin, R. Benioff, M. Campos, B. Jallow, F. Rijsberman, M.I. Budyko, and R.K. Dixon (eds.), 1996: *Adapting to Climate Change: Assessment and Issues*. Springer-Verlag, New York, NY, USA, 475 pp.

Stephens, C., 1995: The urban environment, poverty and health in developing countries. *Health Policy and Planning*, **10(2),** 109.

Sugi, M., A. Noda, and N. Sato, 1996: Will the number of tropical cyclones be reduced by global warming? Implication from a numerical modeling experiment with the JMA global model. In: *Proceedings of the 1996 Spring Meeting of the Japanese Meteorological Society, 21-23 May 1996*. The Japan Meteorological Society, Ohomiya, Japan, p. 37 (in Japanese).

Sukumar, R., H.S. Suresh, and R. Ramesh, 1995: Climate change and its impact on tropical montane ecosystems in south India. *Journal of Biogeography*, **22,** 533–536.

Svitoch, A.A., 1997: *Extreme Rise of the Caspian Sea Catastrophe of Coasts of Dagestan Towns*. Moscow University Press, Moscow, Russia, 203 pp. (in Russian with English abstract).

Swift, M.J., J. Vandermeer, P.S. Ramakrishnan, J.M. Anderson, C.K. Ong, and B. Hawkins, 1996: Biodiversity and agroecosystem function. In: *Biodiversity and Ecosystem Properties: A Global Perspective* [Mooney, H.A., J.H. Cushman, E. Medina, O.E. Sala, and E.D. Schulze (eds.)]. John Wiley and Sons, Chichester, United Kingdom, pp. 261–298.

Tang, Q., 1995: The effects of climate change on resource populations in the Yellow Sea ecosystem. *Canadian Special Publication of Fisheries and Aquatic Sciences*, **121,** 97.

Tang, S.Y., 1992: *Institutions and Collective Action: Self-Governance in Irrigation*. Institute for Contemporary Studies Press, San Fransisco, CA, USA, 151 pp.

Teh, T.T., 1997: *Sea Level Rise Implications for Coastal and Island Resorts: Climate Change in Malaysia*. Universiti Putra, Selangor Darul Ehsan, Malaysia, pp. 83–102.

Terazaki, M., 1999: The Sea of Japan large marine ecosystem. In: *Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management* [Sherman, K. and Q.S. Tang (eds.)]. Blackwell, Oxford, United Kingdom, pp. 199–220.

Thongkrajai, E., P. Thongkrajai, J. Stoeckel, S. Na-nakhon, B. Karenjanabutr, and J. Sirivatanamethanont, 1990: Socioeconomic and heath programme effects upon the behavioral management of diarrhoeal disease in northeast Thailand. *Asia Pacific Journal of Public Health*, **4(1),** 45–52.

Tian, Y.J. and S. Liu, 1999: Humankind's desire and achievements in changing nature seen from three project cases. *Science and Technology Review*, **1,** 36–43 (in Chinese).

Timmermann, A., J. Oberhuber, A. Bacher, M. Esch, M. Latif, and E. Roeckner, 1999: Increased El Niño frequency in a climate model forced by future greenhouse warming. *Nature*, **398,** 694–696.

Tobey, J., J. Reilly, and S. Kane, 1992: Economic implication of global climate change for world agriculture. *Journal of Agriculture and Resource Economy*, **17,** 195–204.

Tonkin, H., C. Landsea, G.J. Holland, and S. Li, 1997: Tropical cyclones and climate change: a preliminary assessment. In: *Assessing Climate Change Results from the Model Evaluation Consortium for Climate Assessment* [Howe, W. and A. Henderson-Sellers (eds.)]. Gordon and Breach, London, United Kingdom, pp. 327–360.

Tri, N.H., N.W. Adger, and P.M. Kelly, 1998: Natural resourcemanagement in mitigating climate impacts: mangrove restoration in Vietnam. *Global Environmental Change*, **8(1),** 49–61.

Trigg, P.I. and A.V. Kondrachina, 1998: Commentary: malaria control in the 1990s. *Bulletin of the World Health Organization*, **76(1),** 11–16.

Tsunekawa, A., X. Zhang, G. Zhou, and K. Omasa, 1996: Climate change and its impacts on the vegetation distribution in China. In: *Climate Change and Plants in East Asia* [Omasa, K., K. Kai, H. Toda, Z. Uchijima, and H. Yoshino (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 67–84.

Turner, R.K., S. Subak, and W.N. Adger, 1996: Pressures, trends and impacts in coastal zones: interactions between socio-economic and natural systems. *Environmental Management*, **20,** 159–173.

Ubukata, H., 2000: The impact of global warming on insects. In: *A Threat to Life: The Impact of Climate Change on Japan's Biodiversity* [Domoto, A., K. Iwatsuki, T. Kawamichi, and J. McNeely (eds.)]. Tsukiji-Shokan Publishing Company, Tokyo, Japan; The World Conservation Union (IUCN), Gland, Swizerland; and IUCN, Cambridge, United Kingdom, pp. 61–70.

UNDP, 1997: *Human Development Report 1997*. United Nations Development Programme, New York, NY, USA, 256 pp.

UNEP, 1999: *Global Environment Outlook 2000*. Earthscan, London, United Kingdom, 398 pp.

UNICEF, 1999: *UNICEF Statistical Data*. United Nations Children's Fund, New York, NY, USA. Available online at http://www.unicef.org/statis/indexr.htm.

United Nations, 1998: *UN World Population Prospects*. United Nations, Population Division, New York, NY, USA.

USDA, 1999: *Production, Supply, and Distribution Database*. Available online at http://usda.mannlib.cornell.edu/data-sets/international/.

Valendik, E.N., 1996: Ecological aspects of forest fires in Siberia. *Siberian Ecological Journal*, **1,** 1–8 (in Russian).

Varlamov, S.M., N.A. Dashko, and Y.S. Kim, 1997: Climate change in the far east and Japan Sea area for the last 50 years. In: *Proceedings of the CREAMS '97 International Symposium*, pp. 163–166.

Verghese, B.G. and R.R. Iyer, 1993: *Harnessing the Eastern Himalayan Rivers: Regional Cooperation in South Asia*. Konark Publishers, New Delhi, India.

Vohra, C.P., 1981: The climate of the Himalayas. In: *The Himalaya Aspect of Change* [Lall, J.S. (ed.)]. Oxford University Press, New Delhi, India, pp. 138–151.

Voskoboynikov, G.M., 1999: *The Change of UV Radiation and Its Impact on the Ecosystems of Russian Arctic Seas*. Report of the Russian Academy of Sciences, Moscow, Russia, Vol. 7, pp. 113–121 (in Russian).

Walker, H.J., 1998: Arctic deltas. *Journal of Coastal Research*, **14(3),** 718–738.

Walsh, K. and A.B. Pittock, 1998: Potential changes in tropical storms, hurricanes, and extreme rainfall events as a result of climate change. *Climatic Change*, **39,** 199–213.

Wang, F., 1996a: Climate change and crop production in China. *Economics of Chinese Country*, **11,** 19–23.

Wang, S., 1996b: Impacts of climate change on the water deficit status and growth of winter wheat in North China. *Quarterly Journal of Applied Meteorology*, **7(3),** 308–315.

WASI, 1997: *World Atlas of Snow and Ice Resources* [Kotliakov, B.M. (ed.)]. Institute of Geography, Russian Academy of Sciences, Moscow, Russia, 262 pp.

Webster, P.J. and S. Yang, 1992: Monsoon and ENSO—selective interactive systems. *Quarterly Journal of the Royal Meteorological Society*, **118,** 877–926.

Webster, P.J., V.O. Magana, T.N. Palmer, J. Shukla, R.A. Tomas, M. Yanagi, and T. Yasunari, 1998: Monsoons: processes, predictability and the prospects for prediction. *Journal of Geophysical Research*, **103(C7),** 14451–14510.

White, A., V. Barker, and G. Tantrigama, 1997: Using integrated coastal management and economics to conserve coastal tourism resources. *Ambio*, **26(6),** 335–343.

White, A., M.G.R. Cannell, and A.D. Friend, 1999: Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment. *Global Environmental Change*, **9,** S21–S30.

Wilkinson, C.R. (ed.), 1998: *Status of Coral Reefs of the World*. Australian Institute of Marine Science, Western Australia, Townsville, MC, Queensland, Australia, 184 pp.

WMO, 1999: *Scientific Assessment of Ozone Depletion 1998.* Global Ozone Research and Monitoring Project Report No. 44, World Meteorological Organization, Geneva, Switzerland, pp. 1.1–12.57.

Wong, P.P., 1992: Impacts of sea level rise on the coasts of Singapore: preliminary observations. *Journal of Southeast Asian Earth Sciences*, **7,** 65–70.

World Bank, 1997: *World Development Indicators*.World Bank, Washington, DC, USA, 231 pp.

World Bank, 1996: *Chao Phraya Flood Management Review, Final Report*. The Royal Thai Government, Thailand.

WRI, 1998: *World Resources, 1998–1999*. World Resources Institute, Oxford University Press, New York, NY, USA, 384 pp.

Xia, D.X., W.H. Wang, G.Q. Wu, J.R. Cui, and F.L. Li, 1993: Coastal erosion in China. *Acta Geographica Sinica*, **48(5),** 468–476 (in Chinese with English abstract).

Xiao, X.M., J.M. Melillo, D.W. Kicklighter, Y. Pan, A.D. McGuire, and J. Helirich, 1998: Net primary production of terrestrial ecosystems in China and its equilibrium responses to changes in climate and atmospheric CO_2 concentration. *Acta Phytoecologica Sinica*, **22(2),** 97–118.

Xu, J. and H. Liu, 1997: Border malaria in Yunnan, China. *Southeast Asian Journal of Tropical Medicine and Public Health*, **28(3),** 456–459.

Yamada, T., H. Fushimi, R. Aryal, T. Kadota, K. Fujita, K. Seko, and T. Yasunari, 1996: Report of avalanches accident at Pangka, Khumbu Region, Nepal in 1995. *Japanese Society of Snow and Ice*, **58(2),** 145–155 (in Japanese).

Yim, C.Y., 1999: The forest fires in Indonesia 1997–1998: possible causes and pervasive consequences. *Geography*, **84,** 251–260.

Yoshino, M., 1998a: Global warming and urban climates: report of the Research Center for Urban Safety and Security, Kobe University Special report no. 1. In: *Proceedings of the Second Japanese-German Meeting, Klima Analyse fur die Stadtplanung*, pp. 123–124.

Yoshino, M., 1998b: Deviation of catch in Japan's fishery in the ENSO years. In: *Climate and Environmental Change, International Geographical Union—Commission on Climatology, Evora, Portugal, 24–30 August, 1988*, 189 pp.

Yu, B. and D.T. Neil, 1991: Global warming and regional rainfall: the difference between average and high intensity rainfalls. *International Journal of Climatology*, **11,** 653–661.

Zhang, X.S., G.S. Zhou, Q. Gao, Z. Ni, and H.P. Tang, 1997: Study on global change and terrestrial ecosystems in China. *Earth Science Frontiers*, **4(1–2),** 137–144.

Zhang, X.S., D.A. Yang, G.S. Zhou, C.Y. Liu, and J. Zhang, 1996: Model expectation of impacts of global climate change on Biomes of the Tibetan Plateau. In: *Climate Change and Plants in East Asia* [Omasa, K., K. Kai, H. Taoda, Z. Uchijima, and M. Yoshino (eds.)]. Springer-Verlag, Tokyo, Japan, pp. 25–38.

Zhou, P., 1991: Likely impacts of climate warming on fresh water fishery. *Fresh Water Fishery*, **6,** 40–41.

Zhu, Z., 1991: Chinese fragile ecological ribbon and soil desertification. *Journal of Desert Research*, **11(4),** 11–21 (in Chinese).

Zou, J.Z. and Y.Wu, 1993: Marine environmental biology. In: *Marine Science Study and Its Prospect in China* [Tseng, C.K., H.Q. Zhou, and B.C. Li (eds.)]. Qingdao Publishing House, Qingdao, China, pp. 663–680.