Chapter 3.6

Climate Change Impact in Agriculture: Vulnerability and Adaptation Concerns of Semiarid Tropics in Asia

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Introduction

There is global consensus that current climate is changing, mainly due to the anthropogenic emissions of green house gases (GHG) (IPCC 2007b). Also, there is widespread concern over long-term climate changes and changes in climate variability through occurrence of extreme weather events such as cyclones, floods, droughts, sea level rise, etc. Agriculture is one sector of the economy that is exposed directly and considerably affected by climate and its changes. Because of the spatially different impacts of climate change, there is a need to understand its context in each region with respect to exposure, expected impacts, vulnerability status, and the response strategies to mitigate, cope, and adapt better with the process of climate change.

This chapter presents an overview of the selected seven countries in semiarid tropics (SAT) of Asia, viz. India, Pakistan, China, Sri Lanka, Bangladesh, Thailand, and Vietnam. This is an effort to build conceptual clarity on the climate change issues in the semiarid regions of these countries. In preparing this chapter, a review of the relevant literature was carried out with the objective of building a clear-cut knowledge on various climate change issues vis-à-vis, impacts vulnerability, and adaptation.

Background and rationale

The background of the above research issue along with the hypotheses and assumptions are as follows:

- Climate variability and change can affect the quality, quantity, and reliability of many of the services natural resources provide through extreme and prolonged exposure to climate shocks. Consequently, there is an impact on the pattern of cropping, income and employment, and other socioeconomic and natural resource variables.
- The small aggregate change in temperature or rainfall will receive little attention from the farmers for whom the major focus is on how climate change will affect the frequency and intensity of extreme weather events such as flood, drought, and dry spell. However,

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particular regions will be affected by even small increase in the climate variables through long-term climate changes. Thus, both long-term changes and short-term variability are important.

- The impacts of climate change on cropping pattern in dryland regions have emerged as a critical concern in recent years as the drylands are suffering already from constrained use of natural resources, particularly water. The cropping pattern changes in these areas have much to do with the natural resource use, income, and living standards of the people. Climate change and variability are assumed to have a significant role in the cropping pattern changes in these regions.
- Changes in the farm household income in an area may be influenced by the climate change pattern over years through affecting the irrigation status, and productivity and production status of different crops.
- Changes in the employment status of farm households in an area may be influenced by the climate change pattern through determining the migration pattern, farm income changes, and livelihood options present with the farm households.
- Vulnerability to climate change and its impacts may be different for women when compared with that of men due to different socioeconomic, cultural, and physical factors especially in the dryland regions with lots of resource, economic, environmental, and social constraints. Thus, it is important to analyze climate change vulnerability and impacts in a gender perspective.
- These changes vary from region to region depending on their development status and thus result in differential impacts on regions at different development levels. Therefore, the factors contributing to the development of a region can have much to do with vulnerability to climate change and climate change response options in that region.
- SAT of Asia are characterized by the presence of inadequate and variable rainfall along with the occurrence of frequent drought and dry spells. The population growth in these marginal lands led to the overexploitation of land and environment degradation. External inputs in agricultural systems are also typically low due to environmental constraints and poor commercial and economic infrastructure, which leads to poor socioeconomic status of these regions and a subsequent exacerbated vulnerability.
- Socioeconomic development status along with the exposure to climate change vis-à-vis incidence of climate change and extreme weather events decide the level of vulnerability and the ability to adapt to climate change in that region.
- The impacts are integrated with adaptation responses of farmers at their farm or household level. Farmers are already adapting in their own way to climate change. The exposure to external shocks of climate change and variability pushes the poor households in the SAT region to adopt adaptation responses through which they can cope better and reduce the vulnerable status of their livelihoods to these changes. These responses ultimately affect or change the livelihood options and strategies available to the farm households.
- The past adaptation strategies, namely indigenous technologies and historically developed agrarian practices and also current adaptive capacities and strategies of farmers are often neglected or overlooked in research.
- Recognizing and enhancing these practices and strategies are more important. These strategies can be supported further based on their usefulness with respect to climate change resilience in agriculture.

Climate change: global context

Climate change is one of the manifestations of the environmental change. It has gained global attention since 1990s when the first assessment report of the Intergovernmental Panel on Climate Change (IPCC), established by the World

Meteorological Organization and United Nations Environment Program, was published in 1990 and when United Nations Conference on Environment and Development developed United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The IPCC has published four comprehensive assessment reports on climate change issues. The fourth assessment report of the IPCC, which was published in early 2007, concluded that earth's climate is changing in a manner unprecedented in the past 400,000 years and global average surface temperature has increased with 0.74 ± 0.18°C in the last century and is projected to increase by another 1.1–6.0°C in this century. The human interference into the earth atmosphere is significant and the past anthropogenic (human-induced) emissions of GHG have already committed the globe to further warming of about 0.1°C per decade for several decades (IPCC 2007a). A global assessment of data since 1970 has shown that it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems (IPCC 2007b).

Concern about the issue of climate change resulted in highlighting two fundamental response strategies, namely, mitigation and adaptation by the UNFCCC. The adoption of mitigation responses seeks to limit the emissions of GHG and enhance sink opportunities so that climate does not change so fast or so much. On the other hand, adaptation responses aim to alleviate the adverse impacts through a wide range of system-specific actions (Fussel and Klein 2002).

Figure 3.6.1 shows the link between adaptation and mitigation responses to climate change issue and clearly illustrates that the mitigation responses limit climate change by reducing GHG emissions and indirectly reduces climate change impacts and vulnerabilities. Adaptation responses, on the other hand, can be either autonomous (people exposed to impacts

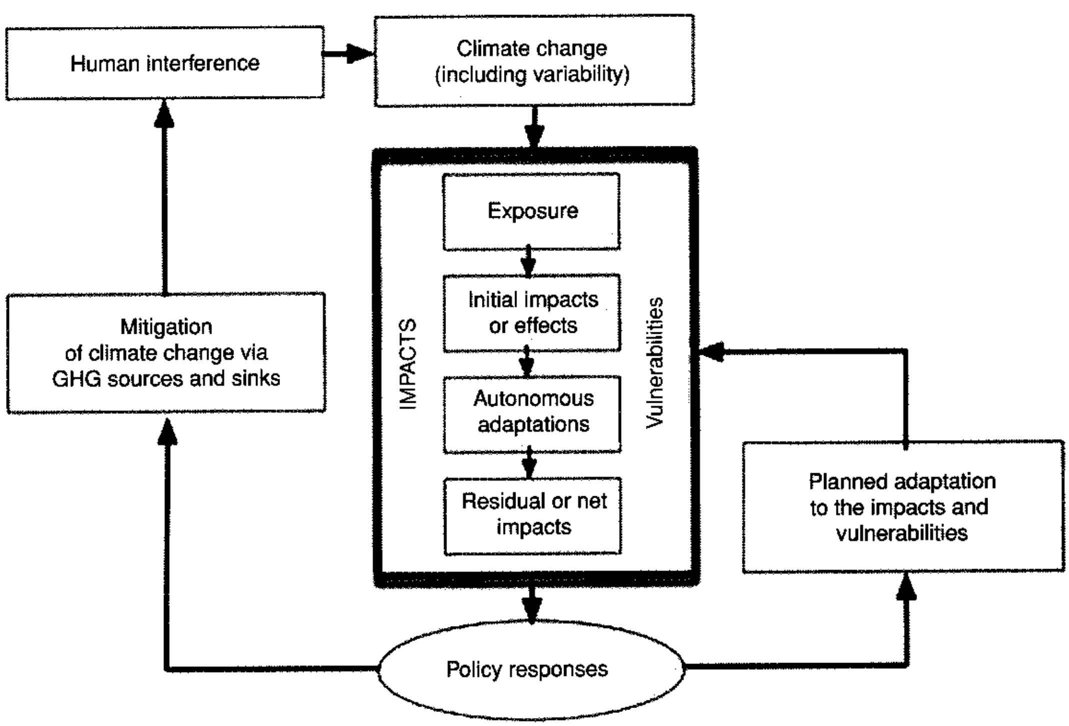

Fig. 3.6.1. Link between climate change adaptation and mitigation.

will spontaneously adapt to changes) or planned, directly to reduce the impacts of and vulnerabilities to climate change.

However, most interest in the past was given to issues related with mitigation by reducing GHG emissions, and less attention was given to adaptation, which was considered initially as a cost of failed mitigation responses by UNFCCC.

Currently, the issue of adaptation has emerged as an urgent policy priority as a means of reducing the losses and prompting action both within and outside the climate change negotiations, particularly after the Third Assessment Report (TAR) of IPCC (Parry et al. 2005; TERI 2005). The importance of adaptation to the climate change and climate variability has become more apparent now as a result of occurrence of climate-related issues such as continuous increase in GHG emissions, lack of progress in developing GHG emission reduction agreements, and increase in negative impacts due to climate change beyond the expected level (Howden et al. 2007).

Climate change vulnerability in semiarid tropics of Asia

Characteristics of the semiarid tropics

Drylands cover approximately 40% of earth's land area. About 33% of total drylands are in Asia (CGIAR 2008; Mwangi and Dohrn 2008; Fig. 3.6.2). There are three types of drylands, viz. arid, semiarid, and hyper-arid lands. SAT cover between 13% and 16% of the earth's land area (Heathcote 1996).

The SAT in the world include parts of 55 countries in the developing world vis-à-vis South and Southeast Asia, sub-Saharan Africa, southern and eastern Africa, and Latin America.

The climate of semiarid regions is generally characterized by inadequate and variable rainfall. SAT have an average rainfall ranging between 300 and 800 mm, and the rainfall variability is significant in terms of both seasonal and annual distribution. The dryland regions with unimodal rainfall pattern generally receive annual rainfall during three months (Kao 2009).

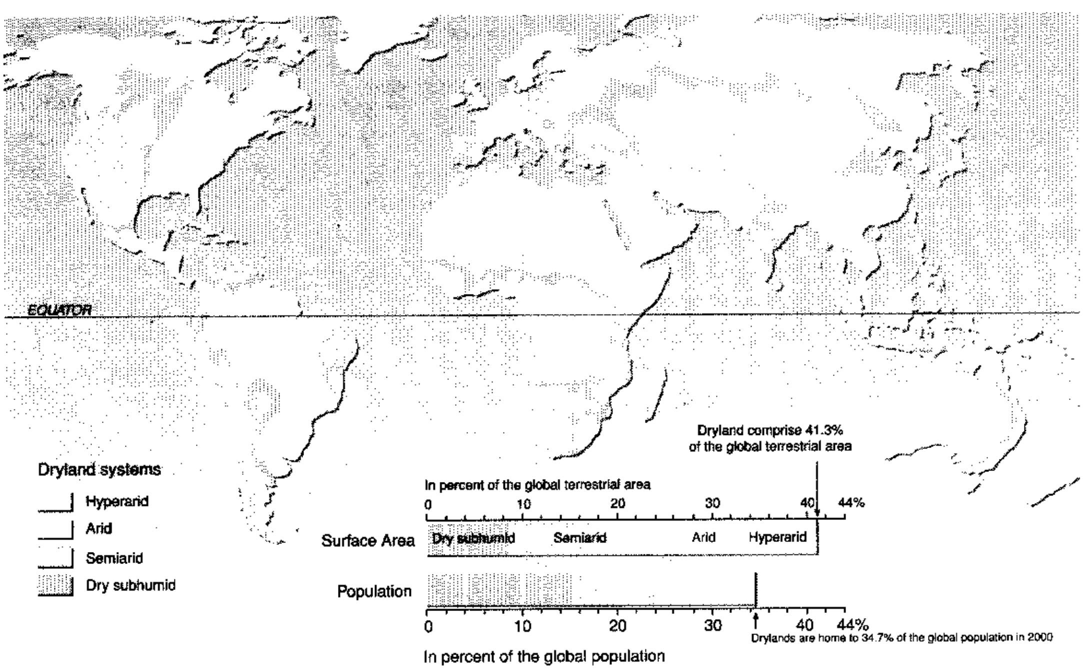

Fig. 3.6.2. Dryland regions of the world. (*Source:* Millennium ecosystem assessment in Kao (2009).)

Watson et al. (1996) reported that people who live on arid or SAT are particularly vulnerable to climate change (Olmos 2001).

Globally, SAT are home to 1.4 billion people (Thurston 1997). Of these, 560 million people are classed as "poor" as they have a daily income of less than US$1, of whom 70% live in rural areas. Semiarid tropical areas in Asia are largely concentrated in India, with some small areas distributed in Pakistan, Myanmar, Thailand, Yemen, and Indonesia. The SAT in South Asia are largely affected with poverty, food insecurity, child malnutrition, and gender inequalities. For example, over 80% of the total SAT poor (and one-third of the total poor in the developing world) live in sub-Saharan Africa and South Asia (Ryan and Spencer 2001).

In the SAT Asia, transformation of subsistence agriculture has not occurred and this led to low productivity growth rate. Over the last three decades, the area planted with sorghum and millet, which are the two important SAT crops, has fallen by nearly one-third. New crops like maize, soybean, and cotton have become popular in the SAT areas because of their rising market demand. Irrigated area under SAT has increased and SAT agriculture has become more diversified. However, land degradation and ground water depletion have eroded the asset base of farmers considerably (ICRISAT 2006).

Because of poor human, natural resource and infrastructural development in the SAT, large proportions of the population are vulnerable to hunger, famine, dislocation, and the loss of both property and livelihood in the face of climatic, social, political, or economic shocks. Both marginality and low level economic development exacerbate and are exacerbated by environmental changes such as dryland degradation and deforestation (Ribot et al. 2009).

Vulnerability contexts of climate change in Asia

To understand the climate change vulnerability, we need to understand the socioeconomic and environmental and natural resources contexts, which decide different dimensions of vulnerability, such as poverty, gender issues, income inequality, environmental degradation, resource access, etc.

Development context

One of the key findings of the Fourth Assessment Report of IPCC Working Group II is addressing nonclimate stresses, which can increase vulnerability to climate change. Another finding is that sustainable development can reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience. Developing countries have lesser capacity to adapt and more vulnerable to climate change damages, just as they are to other stresses. This condition is most extreme among the poorest people (IPCC 2001b). Thus, understanding the underlying development context, which ultimately decides the vulnerability, is important in climate change research.

Table 3.6.1 shows the socioeconomic and natural resources indicators of the selected countries. Low per capita GDP, lower Human Development Index (HDI) rank, low share of forest land, higher poverty incidence, and higher share of agriculture in GDP of these countries indicate their low development status.

The core dimension of vulnerability comes from poverty. Poverty eradication is the primary objective of any development program in developing countries. About 907 million people, who are undernourished, live in developing countries. Of these, 65% live in only seven countries: India, China, the Democratic Republic of Congo, Bangladesh, Indonesia, Pakistan, and Ethiopia (FAO 2008).

Figure 3.6.3 shows undernourishment status of different regions in the world. Asia and Pacific region is highly suffering from undernourishment. With a very large population and relatively slow progress in hunger reduction, nearly two-thirds of the world's hungry live in Asia (583 million in 2007). China and India together

Table 3.6.1. Socioeconomic and natural resources indicators of the selected countries.

Indicators	China	India	Pakistan	Bangladesh	Sri Lanka	Thailand	Vietnam
Total land ('000 sq. km), 2007	9598	3287	796	144	65.6	513.1	331.2
Agricultural land (% of total land), 2007	57.6	54.73	34.29	62.85	35.97	38.49	30.41
Forest land (% of total land), 2007	21.4	20.61	2.28	6.01	28.55	28.07	40.49
Annual population growth (%), 2005-10	0.6	1.5	1.8	1.7	0.5	0.7	1.3
Per capita GDP (US$), 2007	2604	976	996	428	1676	3841	815
Annual GDP growth (%), 2007	13	9.1	6	6.4	6.8	4.8	8.5
Share of Agriculture in GDP (%), 2007	11	18	21	6.8	12	11	20
People living <$1.25/day (%), 2005	15.9	41.6	22.6	50.5	10.33	0.4	22.8
Human Development Index rank, 2008	94	132	139	147	104	81	114

Source: UNDP 2008; WDI 2009.

account for 42% of the chronically hungry people in the developing world (FAO 2008).

South Asia alone accounted for almost all (236 of the 237 million) of the rural poor in SAT Asia and about 63% of the rural poor in the SAT worldwide. This also indicates that about 50% of poor in South Asia is concentrated in the SAT. India's SAT areas have the highest poverty incidence of 24% when compared to other agroclimatic regions (ICRISAT 2006).

Water resources

Climate change will, in many parts of the world, adversely affect socioeconomic sectors, including water resources, agriculture, forestry, fisheries, and human settlements and ecological systems, with developing countries being the most vulnerable (IPCC 2000). In Asia, agriculture is the biggest consumer of water and demanding more water in future.

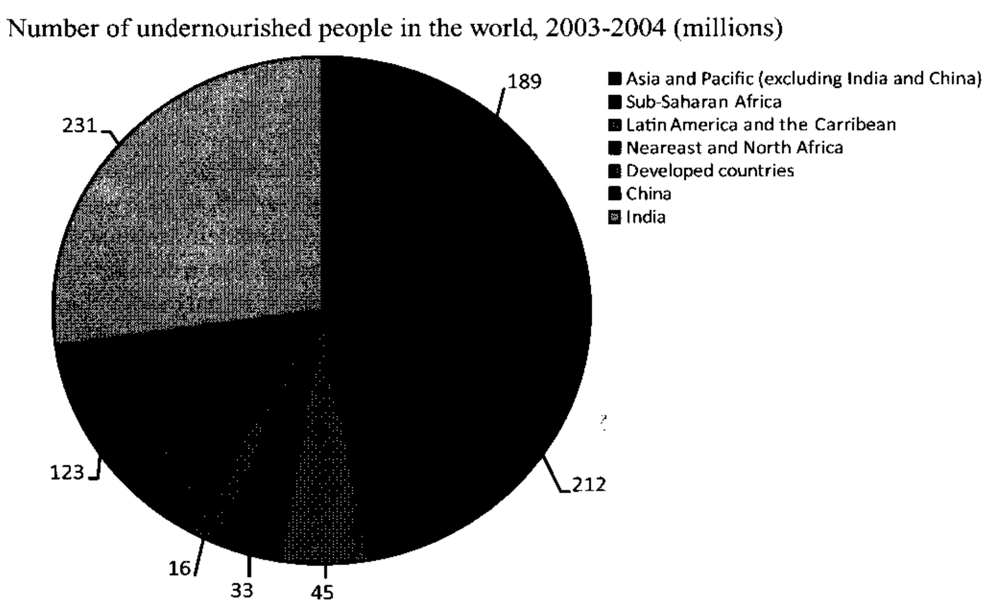

Fig. 3.6.3. World's undernourishment status of different regions. (*Source:* FAO 2008.)

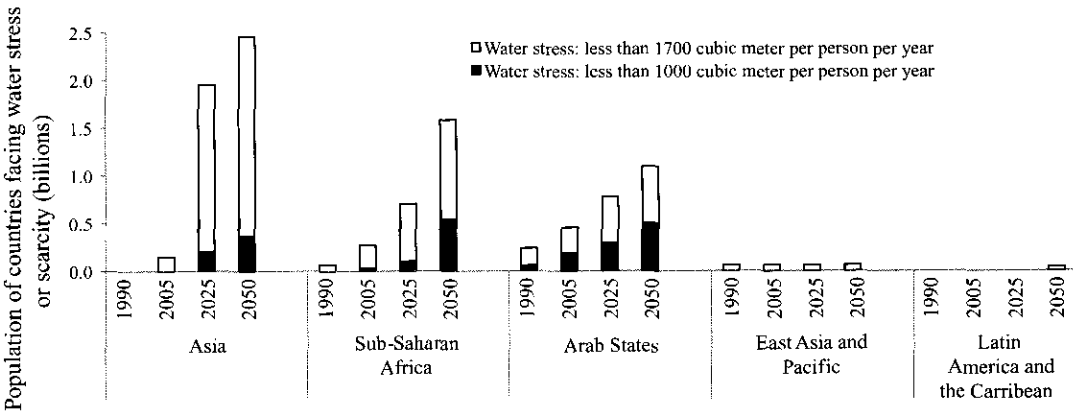

Fig. 3.6.4. Population facing water stress or scarcity projected for 2025 and 2050. (*Source:* UNDP 2007/2008.)

Figure 3.6.4 shows that South Asia is going to be severely affected by water stress and scarcity in the future. About 2 billion people by 2025 and 2.5 billion people by 2050 will be facing water availability problem, either through water stress or through water scarcity.

The Himalayan range contains high altitude glaciers that supply water to many rivers in South Asia. Many people in South Asia are dependent on glacial melt water during dry season. The accelerated melting of glaciers in the Himalayan range is a major climate-related issue in South Asia (HDR 2007/2008). The mountain glaciers in China have retreated, and the trend is accelerating and the rate of sea level rise along China's coasts during the past 50 years was 2.5 mm/a, slightly higher than the global average (NDRC 2007).

In the case of Southeast Asia, during the last decade, many parts of the region have been experiencing increasing water stress, including water shortages and deterioration of water quality due to rapid population and economic growth and climate change. Misuse and overexploitation of water resources has depleted aquifers, lowered water tables, shrunk inland lakes, and diminished stream flows, some to ecologically unsafe levels. Deforestation in some of its important watersheds has also contributed to the reduction of water levels in rivers, especially during dry seasons, while demand for irrigation is another important contributing factor to water shortages.

Thailand has the highest ratio of annual freshwater withdrawal to total internal water resources (41.5%), followed by Vietnam (19.5%) in Southeast Asian region. This indicates the higher vulnerability of Thailand and Vietnam to changes in water resources. About 95% of the total fresh water withdrawal is used for agriculture production in Thailand, whereas it is only 68% in the case of Vietnam, where a considerable share of the available freshwater supply is used for domestic (settlements or residential) and industrial purposes (ADB Report 2009).

The vulnerable nature of water resources to climate change in these countries has many future implications, such as water availability to different uses, cost of irrigation, production and productivity, farm income, etc., as climate change can affect the supply of irrigation water in agriculture.

Economic globalization context

Both climate change and economic globalization will have varying consequences for different sectors of the economy. The agricultural sector represents the convergence of impacts related to climate change and economic globalization.

Economic globalization is indicated by foreign direct investment and growth in international trade. Similar to climate change, globalization is also characterized by uneven impacts on different regions, countries, and social groups. The concept of double exposure comes from the view that exposure to the negative impacts of both economic marginalizations out of the process of globalization and high environmental risks results in negative impacts of both the processes. South Asia and sub-Saharan Africa were left out of the process of globalization and created regional disparities and inequalities that could be one factor determining the vulnerability to climate change among these regions (O'Brien and Leichenko 2000).

In China, investment flows have been focused on coastal ecosystems and western region of the country lagged behind in terms of development. But coastal regions are also vulnerable to climate change. A region can be a double loser when it is vulnerable to climate change and economically marginalized, such as sub-Saharan Africa and South Asia. In some cases, impacts of economic globalization can offset the consequences of climate change. It can be viewed from different perspective, such as regional, sectoral, social groups, or ecosystem (O'Brien and Leichenko 2000).

Thus, understanding the process of climate change and economic processes such as globalization is complex and they are interlinked. The studies will have different outcomes depending on the perspective used.

Climate change impacts in Asia

The IPCC TAR particularly identified the Asian region as most vulnerable to climate-change-related impacts due to its poor adaptive human systems (Lal et al. 2001 in Prabhakar and Shaw 2008).

Climate change trends and projections in Asia

For the tropical Asian region, several countries in tropical Asia have reported an increased trend in surface temperature and a decreased trend in rainfall over the past three decades (Sivakumar et al. 2005).

For SAT, most of the climate change scenarios project worsening of climatic conditions, in the form of more frequent droughts and shorter growing seasons (Ribot et al. 2009).

Table 3.6.2 shows the climate projections for Central and South Asia.

A general warming is expected with a 100% increase in the frequency of extremely warm years. Future changes in drylands precipitation are less well defined. In the context of uncertainty of model outputs, rainfall increase is projected in South Asia with a decreasing trend in Central Asia.

Specifically, tropical cyclones in South Asia are not been observed as a long-term variation in the total number but rather an increase in intensity is suggested. Over most regions, diurnal temperature range (DTR) will reduce due to the increase in night temperatures (Sivakumar et al. 2005; Kao 2009).

Table 3.6.3 shows the climate change trends and projections of the selected countries for the study. It gives the idea that there is a general warming trend in the case of all the countries with a projected increase in warming in future.

Table 3.6.2. Climate projections for different dryland regions.

Region	Temperature (°C)	Precipitation (%)	Frequency of extreme warm year (%)
Central Asia	+3.7	−3	100
South Asia	+3.3	+11	100

Source: IPCC 2007; Sivakumar et al. 2005; Kao 2009.

Table 3.6.3. Climate change: Trends and projections.

	Trends		Future projections	
	Atmospheric temperature	Precipitation	Atmospheric temperature	Precipitation
China	Increased by 0.5~0.8°C during the past 100 years (NDRC 2007)	Decreased average @ 2.9 mm/10 years (NDRC 2007)	Air temperature would rise by 1.3~2.1°C in 2020 and 2.3~3.3°C in 2050 over 2000 temperature	Precipitation increase 2~3% by 2020 and 5~7% by 2050 (NDRC 2007)
India	Warming trend of 0.57°C/100 years (Sivakumar et al. 2005)	Spatial variation in rainfall pattern	Increase in winter and minimum temperature by 4°C (Mall et al. 2006)	Predicted 7–10% increase in annual mean precipitation and decline of 5.25% in winter rainfall and 10–15% increase in monsoon rainfall (Mall et al. 2006)
Pakistan	Increased by 0.35°C an average rate of 0.08°C per decade	Mean annual rainfall has not changed with any discernible trend since 1960 (McSweeney et al. 2009)	An overall increase in temperature 3–5°C over the next century	Increased variability of monsoon with southern regions will benefit (~20%) and northern regions will suffers low rainfall (−5%)
Bangladesh	Increasing trend of 1°C in May and 0.5°C in November during 1985–1998	Rainfall exhibited an increasing trend since 1960	Rise of 1, 1.4, and 2.4°C in annual temperature by 2030, 2050, and 2100, respectively	Precipitation will increase during the summer monsoon (Agrawala 2003)
Sri Lanka	Increasing trend of about 0.30°C per 100 years (Sivakumar et al. 2005)	Increases in diurnal variation (Sivakumar et al. 2005)	Rise of 1.4–2.7°C in average temperature (http://sgp.undp.org/downloads/2002-3.pdf)	Spatial variation in rainfall is predicted
Thailand	An increase from 0.10–0.18°C per decade over 5 decades. (ADB Report 2009)	A long-term decreasing trend in rainfall (Sivakumar et al. 2005)	Temperature increase would be 2–4°C by the end of this century (TEI 2000)	Spatial variation in rainfall
Vietnam	Annual average temperature increased 0.1°C per decade from 1900 to 2000, and 0.7°C, or 0.14°C per decade, during 1951–2000 (ADB Report 2009)	Average monthly rainfall decreased during July and August, and increased during September and November (ADB Report 2009)	An increase in temperature would be of 2–4°C by 2100	Annual rainfall would increase by 5–10% toward the end of this century and also affecting monsoon pattern (ADB Report 2009)

Natural disasters and extreme events in Asia

The TAR of the IPCC, 2001, pointed out that climate change and its variability will exacerbate existing vulnerabilities to droughts and floods in Asia. Tropical cyclones can become more intense. Combined with sea-level rise, this will result in enhanced risk of loss of life and properties in coastal low-lying areas of cyclone-prone countries. Increased precipitation intensity, particularly during the summer monsoon, will contribute to increase in flood events (HDR 2007/2008).

Millions of people living in the low-lying areas of the People's Republic of China (PRC), Bangladesh, India, and Vietnam will be affected by rising sea levels by the end of this century (Wassmann et al. 2004 and Stern 2007 in ADB Report 2009).

At the same time, drier summer conditions in arid and semiarid areas will lead to more severe droughts. India and Pakistan mainly depend on arid and semiarid lands for their cultivation, and these areas already experience frequent natural disasters (HDR 2007/2008). The amount of annual rainfall varies dramatically in drylands. Given the relatively scant seasonal and interannual precipitation, a certain level of rainfall deficiency can easily give rise to the occurrence of drought. In addition, a large DTR is also frequently observed in drylands. Significant fluctuations in diurnal temperatures have a profound impact on the growth of plants in these regions (Kao 2009). Sivakumar et al. (2005) reported an increase in frequency and severity of wild fires in grassland and rangelands in arid and semiarid Asia in recent decades. Figure 3.6.5 shows the damages due to extreme climate events in Asia and Table 3.6.4 depicts the expected trends and projection of climate variability and extreme events.

Impacts of climate change on agricultural production in Asia

Agriculture in the SAT is under inherent climatic and nonclimatic stresses and has evolved under the influence of different constraints arising out of these stresses. Limited fresh water availability, seasonal variation in rainfall, unreliability of rainfall, and degradation of soil resources are few among the numerous constraints. In rainfed systems of the SAT, the constant risk of drought increases the vulnerability of livelihoods and decreases human security. Therefore, drought management is a key strategy for agricultural development in these regions (ICRISAT 2006).

Focusing the issue of climate change concerns of agriculture in the SAT regions is always complex due to the presence of numerous nonclimatic

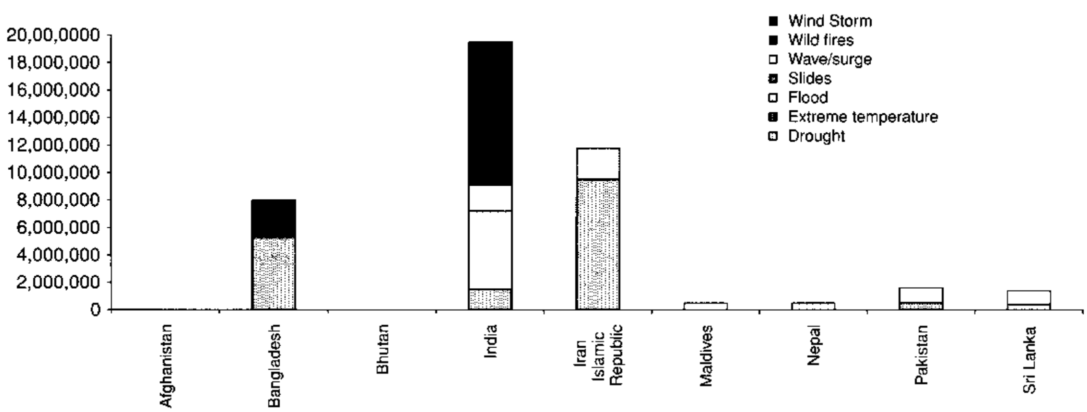

Fig. 3.6.5. Damages due to extreme climate events in Asia. (*Source:* OFDA-CRED (2005) in HDR (2007/2008).)

Table 3.6.4. Climate variability and extreme events: trends and projections.

China	Drought in northern and northeast China and flood in the middle and lower reaches of the Yangtze River and southeast China have become more severe. The annual precipitation in most years since 1990 has been larger than normal and frequent disasters in the north and flood in the south (NDRC 2007)	Possibility of more frequent occurrence of extreme weather climate events would increase (NDRC 2007). In east China, frequency of exceptional floods would increase (Erda et al. 2007)	Arid area would probably become larger and the risk of desertification might increase. The glaciers in the Qinghai-Tibetan Plateau and the Tianshan Mountains would retreat at an accelerated rate, and some smaller glaciers would disappear (NDRC 2007)
India	Increase in extreme rainfall events over northwest India during the summer monsoon. Decline in the number of rainy days in monsoon along east coastal areas. Higher frequent drought following the occurrence of ENSO and 50% of Indian monsoon failures occurrences since 1871 during El Nino years. (Sivakumar et al. 2005). About 22 major drought years during 1871–2002 (Prabhakar and Shaw 2008)	No conclusive increasing or decreasing trends in time series data of flooded areas in various river basins. No identifiable variability in number, frequency, or intensity of tropical cyclones in northern Indian Ocean region over 100 years (Sivakumar et al. 2005). Frequency of severe rainstorms increased over the last 50 years. Number of storms with more than 100 mm rainfall in a day is increased by 10% per decade (UNEP 2007 in HDR 2007/2008)	Number of rainy days in monsoon will be decreased by >15 days and rainfall intensity will rise by 1–4 mm/day. Cyclonic storms will likely to increase in their frequency and intensity increase in heavy rainfall days in summer monsoon (Mall et al. 2006)
Pakistan	Average number of "hot" days and nights[a] per year increased by 20 and 23, respectively, and average number of "cold" days and nights per year decreased by 9.7 and 13, respectively, between 1960 and 2003. (McSweeney et al. 2009). Severe Cyclones in 2007 ravaged southern Pakistan (Kundi 2009)	Annually, "hot" days will occur on 16–25% and 18–38% of day by the 2060s and 2090s, respectively. Hot nights by the 2060s and 2090s, respectively. All projections indicate decreases in the frequency of days and nights that are considered "cold" in current climate (McSweeney et al. 2009)	The proportion of total rainfall that falls in heavy events shows mixed positive and negative changes in projections from different models, however, tend toward increases over the annual average (McSweeney et al. 2009)
Bangladesh	No conclusive increasing or decreasing trends in time series data of flooded areas in various river basins (Sivakumar et al. 2005) of three islands. Extreme flooded years were 1988, 1998, 2002, 2003, and 2004 (Bangladesh 2007)	One-fifth of the country is flooded every year, and in extreme years, two-thirds of the country can be inundated (Mirza, 2002 in Agrawala et al. 2003). Cyclones from the Bay of Bengal decreasing since 1970 but the intensity has increased (Bangladesh 2007)	2°C warming with 10% increase in precipitation would increase runoff in the major rivers significantly Mirza and Dixit (1997). Sea level rise of 0.5 m over the last 100 years has already eroded 65% of three islands (Bangladesh 2007)

(*Continued*)

Table 3.6.4. *(Continued)*

Sri Lanka	A trend of increased lengths of dry periods along with an increasing trend of rainfall intensity, especially after the late seventies (Ratnayake and Herath 2005)	Rising sea levels would cause intrusion of salt water up the rivers and cause salinity problems (http://sgp.undp.org/downloads/2002-3.pdf)	Predict increase in frequent and prolonged droughts, thunderstorms, and sea water level
Thailand	Between 1990 and 1993, rainfall was below normal. 1994–1995 were flood years. In 2005, 11 m people in 71 provinces were affected by water shortages. In 2008, over 10 m people in the agricultural region were affected by drought. About 55 of 76 provinces have suffered, damaging 60,000 acres, mainly rice (Kisner 2008)	Frequency of extreme events includes prolonged flood and drought, landslides, and strong storm surges. More intense storms but less frequent (Jesdapipat 2008 in ADB Report 2009). Mean sea levels trending higher recently (ADB Report 2009)	An increase in coastal erosion is expected (ADB Report 2009)
Vietnam	There were higher frequency droughts following the occurrence of ENSO (Sivakumar et al. 2005). Increased occurrence of extreme rains causing flash floods. Droughts normally associated with El Nino years (ADB Report 2009)	Rainfall intensity has also increased considerably (Cuong 2008 in ADB Report 2009). More frequent occurrence of typhoons, drought and floods, and heat waves (Cuong 2008 in ADB Report 2009). Average increase of mean sea level by 2–3 mm per year	Southern Vietnam would become drier. Tran et al. (2005) predicts that a 1-meter rise in sea level could lead to flooding of 5000 square kilometers of Red River Delta and 15,000–20,000 square kilometers of Mekong Delta (ADB report 2009)

[a]Hot day or hot night is defined by the temperature exceeding 10% of days or nights in current climate of that region or season. Cold days or cold nights are defined as the temperature below which 10% of days or nights are recorded in current climate of that region or season.

stresses, which lead to constraints and uncertainties such as socioeconomic, environmental, and political constraints, which ultimately threatens livelihoods and sustainability of food production across the SAT region.

There is a general agreement at international community working on climate change projections that climate change may lead to significant reductions in agricultural productivity in developing countries. Agricultural production in South Asia could fall by 30% by 2050 if no action is taken to combat the effects of increasing temperatures and hydrologic disruption (IPCC 2007c). Since temperatures in the South Asian continent are already reaching critical levels during the premonsoon season, this further increment would reduce effectively the yields of all crops, including rice (Wassmann and Dobermann 2007).

Sivakumar et al. (2000) summarize that climate variability has been, and continues to be, the principal source of fluctuations in global food production, particularly in the SAT. Data show that the dry tropics, where rainfed agriculture provides 60% of the world's food, will be the most vulnerable to climate change. ICRISAT data shows that increases in temperature will have a significant (8–30%) reduction in grain yields of dryland crops. Consequently, farmers in the SAT will have to adapt their farming practices to cope with the future environmental, social, and economic constraints. Table 3.6.5 shows the

Table 3.6.5. Agriculture impacts due to climate change: trends and projections.

Countries	Trends: Climatic variability	Trends: Extreme events	Projections
China	About 2–4 day advancement of spring phenophase since 1980s (NDRC 2007). Drought-stricken areas widened in northern China and more floods in southern China	By 2030, the crop productivity could decrease by 5–10%. By 2050, it could reduce rice, wheat, and maize by 37%. Irrigation demand would grow in future (Erda et al. 2007)	Increased instability in agricultural production, mainly in wheat, rice, and maize. Changes in distribution and structure of agricultural production as well as in cropping systems and varieties of the crops (NDRS 2007)
India	For 2.5°C, yield loss for rice and wheat would be between 32% and 40%. For 4.9°C, yield losses would be between 41% and 52%	Wheat yields in central India may drop by 2% in a pessimistic climate change scenario (GoI 2004 in HDR 2007/2008)	About 2°C rise in mean temperature and a 7% increase in mean precipitation will reduce net revenues by 8.4% (Kumar and Parikh 2001 in HDR 2007/2008)
Pakistan	Wheat yields are predicted to decline by 6–9% in subhumid, semiarid, and arid area with 1°C increase in temperature (Sultana and Ali 2006 in HDR 2007/2008)	Higher temperatures are likely to result in decline in yields, mainly due to the shortening of the crop life cycle, especially the grain filling period (HDR 2007/2008)	A 0.3°C decadal rise could have a severe impact on important cash crops like cotton, mango, and sugarcane (MoE 2003 in HDR 2007/2008)
Bangladesh	During 1973–1987, 2.18 mt and 2.38 mt of rice were damaged due to drought and flood, respectively. Drought affects annually about 2.32 mha and 1.2 mha in kharif and Rabi seasons, respectively (Bangladesh 2007)	A 4°C temperature increase could reduce rise and wheat production by 30% and 50%, respectively (HDR 2007). Rice and wheat production might drop by 8% and 32%, respectively, by 2050 (IPCC in Bangladesh, 2007)	A net negative effect on the yields of rice (Karim et al. 1996 in HDR 2007/2008)
Sri Lanka	About 0.5°C temperature rise is predicted to reduce rice output by 6%, and increased dryness will adversely affect yields of tea, rubber, and coconut (MENR 2000 in HDR 2007/2008)	In warm, semiarid regions, deficiency of moisture would be a major constraint (HDR 2007–08)	Highest negative impact is estimated by coarse grains and coconut. An increase in the frequency of droughts and extreme rainfall events could result in a decline in tea yield (Wijeratne 1996 in HDR 2007/2008)
Thailand	More than $1.75 billion losses due to floods, storms, and droughts between 1989 and 2002. During 1991–2000, damage to agricultural areas cost up $1.25 billion (Boonpragob 2005)	Increasing temperature reduced crop yield. Saltwater intrusion has affected many agricultural areas	Negative impacts on corn productivity ranged from 5–44%, depending on the location of production
Vietnam	Flooding in the Red River Delta, central Region, and Mekong Delta. The Mekong River Delta flood in 2000 brought severe damage to 401,342 ha of rice, 85,234 ha of farmland, and 16,215 ha of fish and shrimp farms	Rice areas affected by drought doubled from 77,621 ha in 1979–1983 to 175,203 ha in 1994–1998 (Cuong 2008 in ADB Report 2009). Affected by severe saltwater intrusion in agricultural areas	Predicts a decrease in spring rice yields of 2.4% by 2020 and 11.6 % by 2070. Summer rice will be less sensitive to climate impact than spring rice but the yield will also decrease by 4.5% by 2070

agricultural impacts due to climate change in the South Asian countries.

Adaptation to climate change

Adaptation to climate change is a new process for both developed and developing nations. Concrete experience is limited in applying adaptation approaches, and the economic, environmental, and social contexts contribute for uncertainties in different countries. The adaptation line of inquiry reflects the international community's emerging need to prepare for and adapt to climate change and to integrate adaptation issues into core policy and decision-making processes and their funding instruments (Parry et al. 2005; TERI 2005).

Adaptation is important in the climate change issue in two ways: one relating to the assessment of impacts and vulnerabilities, and the other to the development and evaluation of response options (Smit and Pilifosova 2001).

Adaptation potential and strategies

There are many adaptation strategies, which can be followed in particular sectors and regions depending upon their vulnerability and sensitivity to climate change. These are based on experience, observation, and speculation about alternatives that might be created (Smit and Pilifosova 2001).

Adaptation calls for natural resource management (NRM), food security, social and human capital, and strengthening of institutional systems (Adger et al. 2003).

The World Development Report (2008) on "Adaptation to and Mitigation of Climate Change in Agriculture" provides the idea that the public sector can facilitate adaptation through such measures as crop and livestock insurance, safety nets, and research on and dissemination of flood-, heat-, and drought-resistant crops. This report point out that new irrigation schemes in dryland farming areas are likely to be particularly effective, especially when combined with complementary reforms and better market access for high-value products.

Better climate information is another potentially cost-effective way of adapting to climate change. Contingency planning across sectors is suggested to address uncertainty from climate change (World Development Report 2008).

Smit and Pilifosova (2001) summarize that adaptation strategies could be change of topography of land, use of artificial systems to improve water use or availability and protect against soil erosion, change in farming practices, change in timing of farm operations, different crop varieties, public policies and programs, research into new technologies, etc., which can be followed in agriculture.

Different adaptation strategies can be followed in the SAT, namely, improving monitoring mechanism in climate change studies, implementing sustainable agricultural practices, developing of innovative technologies, seeking active participation of local communities, enforcing effective intervention policies, and using strategies for efficient conservation of water (Sivakumar et al. 2005).

Mainstreaming climate change adaptation in development planning in Asia

There is initiation of national-level adaptation to climate change in Asian countries. Several least-developed country members in Asia and pacific have prepared National Adaptation Program for Action (NAPAs), and in India and the PRC, they are undertaking activities in both adaptation research and policy. Nongovernmental organizations (NGOs) and research institutes are also aligning activities toward climate adaptation. Adaptation requires an active and meaningful participation of all the stakeholders.

Climate change has been identified as a serious risk to poverty reduction in developing countries. Thus, adaptation strategies will need to be integrated into poverty reduction strategies in such a way that it incorporates long-term adaptation in the future rather than short-term reactions to disasters to ensure sustainable development. If there is mainstreaming of climate change in development initiatives, then this will bring both immediate benefits as well as strengthen people's ability to deal with future threats (Burton et al. 2002; Huq et al. 2003; Adger et al. 2007).

The following discussion outlines the national-level adaptation strategies in selected countries.

China

China established the National Coordination Committee on Climate Change (NCCCC), which presently comprises 17 ministries and agencies. The NCCCC has done a lot of work in the formulation and coordination of China's important climate-change-related policies and measures, providing guidance for response of central and local government to climate change.

In 2006, China published its National Climate Change Program for adaptation to climate change, and some of the objectives for 2010 being improving grasslands and restoring them from degradation, desertification and salinity, increasing water-use efficiency, reducing vulnerability of water resources, and improving adaptation technology in agriculture.

Some of the technology needs for adaptation to climate change in China, identified in the National Climate Change Program, are high-efficiency water-saving agrotechnologies such as spray and drip irrigation, high-efficiency flood-control, agrobiology, agricultural breeding, new-type fertilizers, disease and pest control, and technology for observation and prewarning of flood, drought, sea level rise, agricultural disasters, etc. (NDRC 2007).

India

India identified the possibilities of water stress due to reduction in fresh water systems leading to threat to agriculture and food security in the first National Communication to the UNFCCC. It also identified strategies specific to drought vulnerability reduction, such as changes in land-use pattern, water conservation, flood warning systems, and crop insurance (Prabhakar and Shaw 2008). Ongoing programs such as watershed development programs, command area development programs, crop diversification, and extension of irrigation facilities to larger areas in addition to various flood control measures in some of the flood-prone areas were identified with a need for common nationwide adaptation strategy like integrated watershed management at local and basin levels (Prabhakar et al. 2009).

The Ministry of Agriculture and Cooperation is responsible for drought management in India. India Meteorological Department and National Center for Medium Range Weather Forecasting (NCMRWF) under the Ministry of Science and Technology are responsible for weather forecasting and drought monitoring. At national level, Crop Weather Watch Group, and at the state level, Weather Watch Group are responsible for assessing the drought and for warning system (Prabhakar and Shaw 2008). The National Disaster Management Authority (NDMA) is the apex authority for disaster management.

Shukla et al. (2003) studied climate change in India and suggested different policy initiatives that would reduce India's vulnerability to climate change, such as faster economic development with more equitable income distribution, improved disaster management, sustainable sectoral policies, and careful planning of capital intensive and climate sensitive long-life infrastructure assets.

Prabhakar and Shaw (2008) suggested no-regrets adaptation options to cope better with drought for India:

1. Enhance the local capacity for drought preparedness and mitigation (capacities of communities and local governments)
2. Improvement in drought prediction and communication (clarity in center–state

relationships in dealing with the natural hazards such as droughts)
3. Improvement in drought monitoring
4. Enhanced operational preparedness for initiating quick response.

Pakistan

In Pakistan, national policies that consider climate change adaptation in their implementation are (1) National Environment Policy (2005), (2) National Sanitation Policy (2006), and (3) National Energy Conservations Policy (2006). Pakistan has established a Global Change Impact Studies Centre, Prime Minister's Committee on Climate Change, a NDMA, National Implementation Committee for NEP, and at the top of all these is the Pakistan Environmental Protection Council as various national initiatives.

Pakistan views that disaster risk reduction and climate change responses as a common sphere of concern. Pakistan promulgated a National Disaster Management Ordinance. Also, a Disaster Reduction Unit established by UNDP. The organizations responsible for disaster management are NDMA, The Federal Flood Commission, Emergency Relief Cell, and Pakistan Meteorological Department (Kundi 2008).

Bangladesh

Bangladesh submitted its National Adaptation Programs of Action (NAPA) with the UNFCCC Secretariat in November 2005. The Climate Change Cell has a mandate to continue the NAPA process and facilitate implementation of NAPA. The Comprehensive Disaster Management Program has the goal of mainstreaming disaster management and risk reduction into national policies, institutions, and development processes and to facilitate management of long-term climate risks and uncertainties (Government of the People's Republic of Bangladesh 2005 in HDR 2007/2008). The adaptation measures for agriculture that have been prioritized in Bangladesh NAPA are as follows:

- Promoting adaptation to coastal crop agriculture to combat salinity intrusion through maize production under Wet Bed No-tillage Method and *Sorjan* systems of cropping in tidally flooded agroecosystem.
- Adaptation to agriculture systems in areas prone to enhanced flash flooding—northeast and central region through no-tillage potato cultivation under water hyacinth mulch in wet sown condition, and vegetable cultivation on floating bed.
- Promotion of research on drought-, flood-, and saline-tolerant varieties of crops to facilitate adaptation in future.
- Exploring options for insurance and other emergency preparedness measures to cope with enhanced climatic disasters such as flood, cyclones, and drought (Bangladesh 2007).

Bangladesh is set to officially release three flood-tolerant rice varieties that would help farmers prevent up to a million tons of annual crop loss caused by flash floods. The development of salinity-tolerant and early maturing rice varieties by research organizations is a recent technological development to address salinity and flash flood, respectively, for crop agriculture. A new Climate Change Strategy and Action Plan have been developed by the Government of Bangladesh in 2009 in consultation with civil society, including NGOs, research organizations, and the private sector. It was built on the NAPA. As per this, the needs of the poor and vulnerable, including women and children, will be prioritized in all activities implemented under the Action Plan.

Sri Lanka

Sri Lanka was the first country in Asia to prepare a National Environmental Action Plan in 1992, with further updates published in 1998 and 2003. Priority environmental issues, from a poverty perspective, were identified. Sri Lanka's Poverty Reduction Strategy Papers in March 2003 was considered to be reasonably successful by the

World Bank Environment Department in mainstreaming these key environmental issues. Also, community-driven development has a major role in its success (IDS 2006).

Being a small island nation, Sri Lanka falls into the UNFCCC and IPCC's category of "vulnerable" small island nations under serious threat from various climate change impacts, such as sea level rise and severe floods and droughts (UNFCCC 1992; IPCC 2001a; Yamane 2003).

The national communication report to UNFCCC proposed a number of adaptation measures in agriculture, such as developing tree crop agriculture, developing drought-resistant rice varieties, changing land use patterns in landslide-prone areas, making farmers aware of climate change, and changing irrigation methods (Sri Lanka 2000; Yamane 2003).

Thailand

In Thailand, the Ministry of Natural Resources and Environment (MONRE) is responsible for government policy, within which the Office of Natural Resources and Environmental Policy and Planning (ONEP) is the national focal point to the UNFCCC. The National Climate Change Sub-committee was established under the National Environmental Board after the country ratified the UNFCCC. In July 2007, the government upgraded the National Climate Change Sub-committee to the National Climate Change Committee, chaired by the prime minister. Technical subcommittees are also established under the national committee to support different aspects of climate change issues, including mitigation, vulnerability, and adaptation. Thailand has already developed the country strategic plan on climate change and is currently developing its 10-year climate change plan. A key policy aim is to strengthen the links between measures to address sustainable development and those to address climate change (ADB Report 2009).

In Thailand, national climate change adaptation plans and implementation for agricultural sector includes germplasm banks for major crops, increasing the use of degraded land for flood control, specific policy on food security, improving water efficiency in cropping and appropriate use of land, experimenting crops in marginal land areas, financial and technological support for local communities in adaptation, and forest set-aside program (ONEP 2008; ADB Report 2009).

Vietnam

MONRE is the lead government agency for implementing the UNFCCC and the Kyoto Protocol, and for all climate change activities. Vietnam submitted its initial national communication to the UNFCCC in 2003. The NTP (National Target Program) is officially described as the main framework for the management and coordination of CC activities. National strategies are designed to reduce the risk of disasters, and the key institution is the Central Committee for Flood and Storm Control.

Climate change adaptation projects are particularly emerging in the Central Coast Region. Most project activities focus on local levels and are linked to or integrated within ongoing support by donors and international NGOs to national entities and communities for drought, flood, and typhoon preparedness and response. In the Mekong Delta, adaptation measures were tried at the farm level, community level, and national level (Suppakorn et al. 2006).

Vietnam does not yet have national or local climate change adaptation strategies, and national and local capacity building is urgently needed to ensure that policy responses are adequate and effective (Chaudhry and Ruysschaert 2007).

Even though these countries have already started their adaptation planning at national level, still they need to act at a faster and sooner pace concerning progress in mainstreaming climate change adaptation into sustainable development planning. These policies and institutions are constrained by lack of knowledge and technology, resources, interest, etc., and hinder the process in these developing countries.

Farm-level adaptation to climate change

Farmers are already adapting in their own way to climate change, which is happening. (World Development Report 2008). Adaptation depends on the cost of adaptive measures, existence of appropriate institutions, access to technology, and biophysical constraints such as land and water resource availability, soil characteristics, genetic diversity, and topography, etc. (Sivakumar et al. 2005).

Kelly and Adger (2000) argue that rather than to synthetically identify several regions and sectors as vulnerable and propose "new" ways to adapt to the climate change risk as recommended by the climate change regime, recognizing and enhancing the current adaptive capacities and strategies that are often neglected or overlooked are more important. This implies that indigenous technologies and agrarian practices can be supported to enhance adaptation strategies. This can be done through identifying the historically developed traditional capacities and specific strategies, which are being adopted to cope with the particular climate situation such as drought and flood and also by giving more research attention to improve and enhance their efficiency, effectiveness, and adaptability with respect to the current and future extreme climate events.

Adaptation efforts can be made more effective with enhanced coordination and institutional support from government (OECD 2008; ADB Report 2009).

This research effort should be seen as complementing the aforementioned arguments, and it will identify the adaptive capacity and adaptation strategies of the selected regions, considering the importance of currently adopted adaptation strategies by farmers of a particular region with a specific climate change and vulnerability status. Furthermore, the authors wish to support the argument that climate change adaptation at different levels needs to be provided with technological, research, institutional, and policy support from different sources, viz. government, NGOs, local institutions, community-level groups, or societies, and also international cooperation between different regions in order to strengthen and improve the adaptive capacity of farmers/region.

Resilience mechanisms and coping strategies

Climate change is a dynamic process and there is no silver bullet to address the impacts of climate change effects. Adaptation alone cannot help coping with climate change effects. Adaptation and mitigation should go hand-in-hand. A blend of crop improvement and NRM technologies help in overcoming the climate change effects in agricultural production. Better forecasting methods, best-bet interventions, NRM and knowledge sharing in the short run, use of adapted crop cultivars and appropriate crop, and NRM methods and better policies holds the key in the long run to cope with climate change. Some of the current products and technologies in agriculture that help in coping up with climate change are presented below.

- Water management
  Water is the critical input for agriculture, and across the SAT, water is the most limiting factor for crop production. Predictions of future rainfall are less certain. It is generally agreed that climate change will modify rainfall, evaporation, runoff, and soil moisture storage, while warmer temperatures would lead to an increase in crop water requirements. Improving crop production under the scenario of reduced supply and increased demand depends to a large extent on overcoming soil moisture problems through better capture and storage of rainwater and through improved use efficiency. Much of the past work on agricultural water management focused on managing the water at plot level. The amount of water that can be conserved and utilized within the plot

through soil management practices is limited by the rooting depth of the crop and the available water storage capacity of the soil. These limiting factors often combine to result in insufficient water to sustain crop growth during prolonged dry spells. Water harvesting technologies with storage components have not received much attention (Rockstrom 2000). A significant knowledge gap exists on the economic viability of such systems. Creating storage structures and irrigation systems require substantial investment, which is beyond the capacity of most rural communities. Almost 95% of the developing countries' water withdrawals are used to irrigate farmlands. Therefore, water policy to make more efficient use of water for agriculture is crucial. This involves understanding water flows and water quality, improved rainwater harvesting and water storage, and diversification of irrigation techniques. Such considerations will need to be framed in the context of rapidly expanding populations that are predicted to exacerbate intersectoral competition for abstracted water supplies. Robust irrigation infrastructure may be necessary to cope with climate change risks in the short to medium term. Maintenance of existing infrastructure too deserves early attention.

- Advance warning and disaster management
  Enhancing adaptive capacity of South Asian populations and ecosystems will require multiple actions at various levels. Regional cooperation mechanisms on adaptation need to be addressed on a high-priority basis, especially in dealing with trans-boundary issues such as integrated river basin management, forest fire management, and early warning systems. Establishment of advance warning systems, climate proofing of infrastructure, and keeping the disaster management system in high alert are very critical in coping with the natural calamities.
- Microdosing of fertilizers
  Most soils in SA are both thirsty and hungry. While advocating better soil and water conservation practices, it is important to rectify the soil's severe phosphorus and nitrogen deficiency with mini-doses of fertilizer—just one-sixth of the amounts used in developed countries. This practice, called "microdosing" (application of fertilizer about a soda-pop bottle capful per plant) makes the roots to develop early and capture water and nutrients that otherwise would have gone to waste. Even with fertilizer costs approximately three times higher in Africa than in those in the developed world, microdosing is profitable and has resulted in yield increases averaging around 50% in thousands of trials with millet, sorghum, and maize in West and South Africa (Tabo et al. 2005). The same technology can be effectively used in drylands of South Asia.
- Developing climate resilient crops
  (a) Submergence tolerance
  Water inundation due to flash floods is a major problem in Bangladesh and eastern India, where rice is the predominant food crop. Poor drainage facilities in these areas further complicates the problem. Development of submergence-tolerant rice cultivars is the best option under such conditions. Researchers at IRRI and the University of California-Davis identified a submergence-tolerance gene (Sub 1) in the Indian rice variety FR13A and used it in development of submergence-tolerant rice varieties for cultivation in South and Southeast Asia (Xu et al. 2006). These varieties offer scope to cope with the water inundation with high rainfall.
  (b) Stay-green trait to combat the heat and drought
  Crops such as sorghum and pearl millet—staple cereal grains and fodder crop grown by subsistence farmers in sub-Saharan Africa and the Indian subcontinent—are the most heat- and drought-hardy crops. Researchers at ICRISAT and elsewhere used conventional breeding and marker-assisted selection to identify and isolate genes and improve sorghum for

"stay-green" trait that allow the plant to mature normally in low-moisture, high-heat stress areas. "Stay-green" genes delay the senescence of leaves, help the normal grain filling, and reduce the incidence of lodging (Reddy et al. 2007). Crops/cultivars (e.g., sorghum hybrid parents ICSR 21002, ICSV 21011, and ICSB 371) with stay-green trait form an important tool to cope with the drought stress in drylands.

(c) Exploitation of photoperiod sensitivity
Most crops are photoperiod-sensitive, and this trait can be exploited for boosting the crop yields under variable rainfall. For example, in sorghum and pearl millet, earlier workers developed photoperiod-sensitive breeding lines that give farmers an added tool to adapt to rainfall variability. These plants mature at the time of year when conditions are most likely to be favorable for grain development, regardless of when they are planted (Clerget et al. 2007). Photoperiod-sensitive sorghum and pearl millet will adjust their flowering and grain filling at a roughly constant calendar date, which tends to be the period when the rains have stopped, but there is still enough soil water to complete grain development.

(d) High temperature tolerance
Pearl millet and sorghum can tolerate temperatures above 40°C and set seed. Some of the pearl millet hybrids developed by private sector in India such as 9444 and 86 M 64 found yielding high under temperatures as high as 44°C during summer season in India. Currently, they are highly popular with the farmers in major pearl millet growing states of Rajasthan, Haryana, and Gujarat in India.

Studies on impact of temperature increase on rates of crop growth and yield (Cooper et al. 2009) indicate that there will be reduction in "time to maturity" of cultivars. This means in a warmer world, a currently defined "medium duration" type will become a "short-duration" type. Considering this, the crop improvement programs in future should focus on medium to late maturing genotypes with heat tolerance and pest and disease resistance to deal with the yield reduction resulting from temperature increase.

- Knowledge sharing and policy perspectives
Capacity enhancement of stakeholders is very critical, particularly on usage of weather forecasts, climate-adapted cultivars, resource conservation practices, and market intelligence. On-farm testing of products and technologies and village-level studies on coping mechanisms give valuable information. Addressing new climate conditions will require complex policies and adjustments at many levels in developing country agriculture.

Policy is critical in shaping the coping mechanisms. However, climate policy alone will not solve the climate change problem. Climate outcomes will be influenced not only by climate-specific policies but also by the development path chosen (IGES 2008). Asia and Africa, which are already experiencing the adverse impacts of climate change, cannot afford to "wait and see" or follow the historic, unsustainable, carbon-intensive development path of industrialized countries. Developing countries in Asia and Africa have an outstanding backlog of sustainable development and poverty reduction priorities, into which climate change mitigation and adaptation policies must not be integrated.

Conclusions

Research on long-term climate change was the major issue focused in early climate change studies. Recently, climate variability studies have obtained a significant attention from the climatic researchers. This research effort is looking into both the long-term changes and short-term variability in climate.

The above discussions imply that countries, particularly in the SAT, are vulnerable to the current climate situations and climatic shocks in future. Thus, understanding the nature and degree of vulnerability is the initial concern of any climate change study to build adaptation strategies along with understanding the ground level adoption of adaptation strategies to cope with the current climatic situation.

On the basis of these discussions, this chapter aims to draw attention to three issues, which are being addressed through the ongoing research efforts at ICRISAT and elsewhere. They are as follows:

1. The first aim of this research effort is to understand the climate change context (both socioeconomic and environmental/biophysical), which decides the vulnerability of the region. This provides a systematic investigation on the argument that degree of climate change vulnerability depends on socioeconomic, political, and environmental factors, and the results will help to suggest on development of various strategies and policies to address different dimensions of climate change vulnerability in an integrated way.
2. The next step will entail the linking between changes in climate and climate variability and the changes in different aspects such as cropping pattern, income and employment status, and gender issues of vulnerability to climate change along with institutional and policy reforms over the years. Here, the main aim is to increase the understanding of ongoing and future climate change impacts and reinforce the need for measures to deal with climate change. This will empirically help understand, test, and argue the links between climate change risk and changes in socioeconomic development status of a region as part of poverty reduction by looking into the impacts of climate change on these aspects.
3. Another major focus is recognizing the past and current coping and adaptation strategies adopted in the farm households to cope with the climate change impacts. This will help to combine and link the traditional, local, and indigenous knowledge on climate change with the scientific knowledge on climate change.

This research is therefore a comprehensive effort to understand and analyze the vulnerability to and impacts of climate change and the adaptation strategies of farmers in the selected regions. It is expected that by addressing the above three issues, this study will help addressing the climate change challenge in the semiarid regions of Asia through providing suggestions on strategies and policies to reduce the vulnerability and to strengthen adaptive capacity, and on adaptation opportunities and options of the farmers to cope better with the future climate change.

Future line of investigation

To explore further the issue of climate change adaptation, research into the following areas will need to be explored further.

1. Identify the constraints in, and opportunities for, adoption of adaptation strategies within SAT of Asia. Also, there is a need to identify the constraints and gaps in resources for adaptation strategies.
2. Sociological approach to vulnerability and adaptation, including the role of social capital, social networks, and institutions in enhancing resilience to climate change.
3. Recognize the effectiveness of adaptation strategies and also look into how adaptation itself can lead to constraints for households.
4. Exploring the best practices or strategies and identifying the ways to enhance its capacities and opportunities, which provides reduced climate change vulnerability and improved adaptive capacity.
5. In agriculture, early warning and climate forecasting is very much essential to avoid losses during natural calamities. So, it is necessary to develop a regional cooperation for information exchange about climate change, including early warning and forecasting. Also, it is important internalize the crop

adaptation research to climate change in all the crop improvement programs in the region, prioritizing the major impacts of climate change effects on crop production in the respective country/region.

This will help in laying the foundation for developing, implementing, and monitoring adaptation strategies in the SAT in Asia and to become more resilient to climate change in future.

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