Climate Change Resilience in Agriculture: Vulnerability and Adaptation Concerns of Semi-Arid Tropics in Asia

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Introduction

There is global consensus that climate is changing mainly due to the anthropogenic emissions of green house gases (IPCC, 2007b). Also, there is a 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 exposed, directly and affected considerably by climate and its changes. Due to 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.

Semi-Arid Tropics (SAT) of Asia are characterized by the presence of inadequate and variable rainfall along with occurrence of frequent droughts and dry spells. The population growth in these marginal lands has led to over-exploitation of land and degradation of environment. External inputs in agricultural systems are low due to environmental constraints and poor marketing and economic infrastructure, which depict a poor socio-economic status of these regions and a subsequent exacerbated vulnerability.

The socio-economic development status along with the exposure to 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.

In order to set the platform for the International Crops Research Institute for Semi Arid Tropics (ICRISAT) research effort on "Vulnerability to Climate Change: Adaptation Strategies and Layers of Resilience", a major study places its focus on the semi arid tropics of Asia, particularly in seven countries, viz. India, Pakistan, China,

Sri Lanka, Bangladesh, Thailand, and Vietnam. This paper is an effort to build conceptual clarity on the climate change issues in the semi arid regions of these countries. In preparing this paper, 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. These concepts are depicted below:

Climate Change

Many definitions for climate change, vulnerability and adaptation to climate change are found in literature. In 1992, United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." In 2001, the Intergovernmental Panel on Climate Change (IPCC), which is the major scientific body associated with climate change at the international level, defined it as "any change in climate over time, whether due to natural variability or as a result of human activity". The major concepts associated with climate change issue are impacts, vulnerability, adaptation and resilience.

Impacts

IPCC (2007) defines climate change impacts as the effects of climate change on natural and human systems. It can be of two types: potential impacts and residual impacts.

Potential impacts: These may occur given a projected change in climate without considering adaptation.

Residual impact: These are the impacts of climate change that would occur after adaptation measures.

Vulnerability

Vulnerability is defined by IPCC in 2001 as the "degree to which the system is susceptible to, or unable to cope with the adverse effects of stresses, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of change in stresses to which a system is exposed, its sensitivity, and its ability to adaptation or adaptive capacity".

The literature on natural disaster defines vulnerability as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (Paavola, 2008).

Vulnerability can be viewed as "a function of exposure, sensitivity and adaptive capacity". The term "exposure" addresses the incidence of climate change impacts, the term "sensitivity" addresses the capacity of actors to be affected by climate change impacts and the term "adaptive capacity" or "resilience" (suggested by Turner *et al.*,

2003) addresses ability of actors to shield themselves and to recover from adverse climate change impacts. Vulnerability thus comes from social and physical factors; the physical factors concentrate on exposure and sensitivity and social factors account for assets, distribution of income, class, etc. This means environmental and social systems together construct the vulnerability of households in a context dependent way (Paavola, 2008). Moser (1998) has argued that vulnerability is closely linked to asset ownership. The more the assets people have, the less vulnerable they are, and the greater the erosion of people's assets, the greater is their insecurity. The vulnerability also varies across geographical and temporal scales and must be addressed within complex and uncertain conditions and hence calls for interdisciplinary and multiple expertise (TERI, 2005).

Chaudhuri et al.
households will be poor, if not so currently, and if they are currently poor, the risk that they will remain poor. Poverty is therefore an *ex post* measure of wellbeing, and vulnerability an *ex-ante*. In a vulnerability framework, the poor are considered active agents, and interventions can build on their strengths (Baschieri, 2009).

According to numerous authors who work on vulnerability issues, poverty and also its causes such as inequality and marginalisation are among the most important determinants of vulnerability (Adger and Kelly, 1999; Ribot et al. 1996; Olmos, 2001). However, some others have argued that both the wealthy and the poor could be adversely affected by the impact of extreme weather events (O' Brien and Leichenko, 2000; Olmos, 2001).

Adaptation

The definition of adaptation given by IPCC is "adjustments in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts. This term refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change" (IPCC, 2001a).

African Development Bank (ADB, 2003) defined it as "the ability to respond and adjust to actual or potential impacts of changing climatic conditions in ways that moderate harm or take advantage of any positive opportunities that the climate may afford" (IDS, 2006).

The Department for International Development (DFID) of UK in 2006 defined it as "adaptation is about reducing the risks posed by climate change to people's lives and livelihoods" (IDS, 2006).

Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages.

Various types of adaptation can be distinguished as follows: (i) Anticipatory or reactive, (ii) Autonomous or planned, (iii) Private or public, (iv) Short-term or long term, (v) Localised or widespread, and (vi) Farm level or policy level.

Reactive adaptation takes place after the initial impacts of climate change have occurred and anticipatory adaptation takes place before impacts become apparent.

Human and natural systems will to some extent adapt autonomously and that planned adaptation can supplement autonomous adaptation. However, options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems (IPCC 2001:6-8, in Olmos, 2001). The planned adaptation is a consequence of deliberate policy decisions, based on the awareness that conditions have changed or are expected to change that some form of action is required to maintain a desired state. Autonomous adaptation involves changes that systems will undergo in response to changing climate, irrespective of any policy, plan or decision (TERI, 2005).

The adaptation occurs at two main levels, one at the farm level that focuses on micro analysis of farmer decision-making and the second at the national level or macro level that is concerned with agricultural production at the national and regional scales and its relationship with national and international policies (Bradshaw *et al.,* 2004; Kandlinkar and Risbey, 2000)

Resilience

IPCC (2007) defines resilience as "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change". UNISDR (2008) defines resilience as the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

Climate Change in the 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 Organisation (WMO) and United Nations Environment Programme (UNEP), was published in 1990 and United Nations Conference on Environment and Development (UNCED) developed United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The IPCC has published four comprehensive assessment reports on climate change issue. 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 the global average surface temperature has increased with 0.74 ± 0.18 °C in the twentieth 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 greenhouse gases (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, 2007 b).

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 GHGs 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 1 shows the link between adaptation and mitigation responses to climate change issue. It clearly illustrates that the mitigation responses limit the climate change by reducing GHG emissions and indirectly reduce the climate change impacts and vulnerabilities. Adaptation responses, on the other hand, can be either autonomous (people exposed to impacts will spontaneously adapt to changes) or planned, directly to reduce the impacts of and vulnerabilities to climate change.

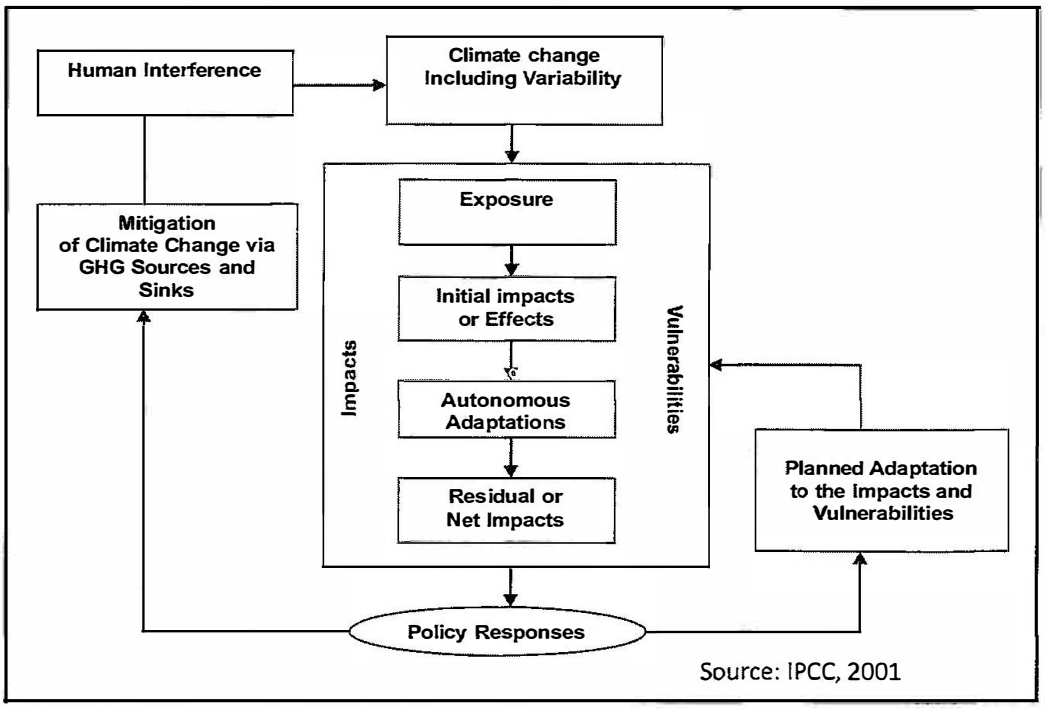


Figure 1. Link between climate change adaptation and mitigation

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 of IPCC

(Parry *et al.*, 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 the Semi-Arid Tropics of Asia

Characteristics of the semi-arid tropics

Drylands cover approximately 40 percent of Earth's land area and 33 percent of total drylands are in Asia (CGIAR, 2009; Mwangi and Dohrn, 2008). There are three types of drylands, viz. arid, semi-arid and hyper-arid lands. Semi-arid tropics cover 13-16 percent of the earth's land area (Heathcote, 1996).

The semi-arid tropics (SAT) in the world include parts of 55 countries in the developing world vis-a-vis South and South-East Asia, Sub-Saharan Africa, Southern and Eastern Africa, and Latin America.

The climate of SAT is generally characterized by inadequate and variable rainfall. The SAT have an average rainfall ranging between 300mm 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). Watson et al. (1996) reported that people who live on arid or semi- arid tropics are particularly vulnerable to climate change (Olmos, 2001).

Globally, SAT is 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 one US dollar, of whom 70 percent live in the rural areas. Semi-arid 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 percent 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, resulting in low rate of productivity growth. Over the past three decades, the area planted to 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 in SAT has increased and the agriculture has become more diversified. However, land degradation and groundwater 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 loss of both property and livelihood in the face of climatic, social, political or

economic shocks. Marginality and low economic development both 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 socio-economic, 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 of Working Group II of the IPCC is addressal of non-climate 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 therefore are more vulnerable to climate change damages, just as they are to other stresses. This condition is on extreme among the poorest people (IPCC, 2001b). Thus, understanding the underlying development context, which ultimately decides the vulnerability, is important in climate change research.

The socio-economic and natural resource indicators have been shown in Table 1 for the selected countries. Low per capita gross domestic product (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 depict their low development status.

Table 1. Socio-economic and natural resource indicators of the selected countries

Indicators	China	India	Pakistan	Bangladesh	Sri Lanka	Thailand	Vietnam
Total land (1000 sq km)- 2007	9598	3287	796	144	65.6	513 1	331.2
Agricultural land (% to total land)- 2007	57 6	54 73	34.29	62 85	35.97	38 49	30 41
Forest land (% to 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
GDP growth, (Annual, %) – 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 on < $1.25/ day(%)– 2005 ppp	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

Sources UNDP (2008), WDI (2009), FAOSTAT (2009)

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

Figure 2 shows the undernourishment status of different regions in the world. The Asia and Pacific region highly suffer 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 account for 42 percent of the chronically hungry people in the developing world (FAO, 2008).

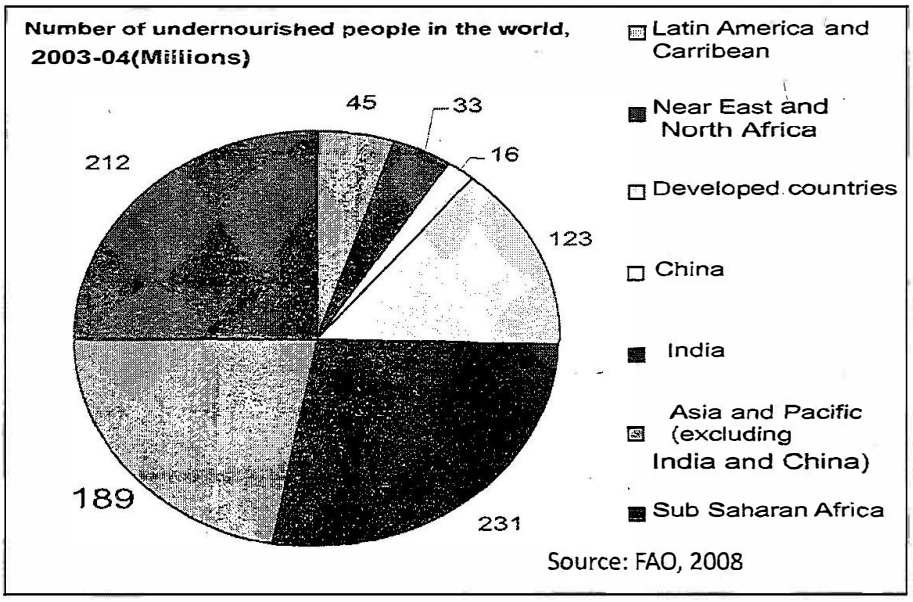


Figure 2. Undernourishment status of different regions of tth thhth the world

South Asia alone accounted for almost all (236 million of the 237 million) of the rural poor in SAT Asia and about 63 percent of the rural poor in the SAT worldwide. This also indicates that about 50 percent of the poor in South Asia are concentrated in the SAT.

Water resources

Climate change will, in many parts of the world, adversely affect socio-economic 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 will demand more water in future.

Figure 3 shows that South Asia is going to be severely affected by water stress and water scarcity in the future. About 2 billion and 2.5 billion people will be facing water

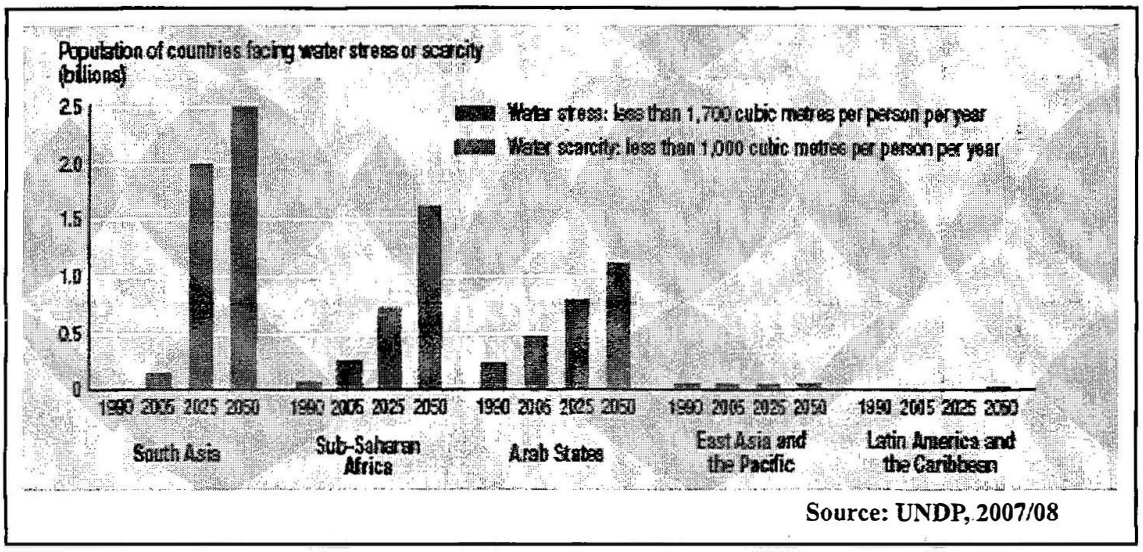


Figure 3. Population facing water stress or scarcity projected for 2025 and 2050

availability problem, either through water stress or through water scarcity by 2025 and 2050, respectively.

The Himalayan range contains high altitude glaciers that supply water to many rivers in South Asia. These rivers provide water to more than half of the world's population. 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 (UNEP, 2007). 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).

For the past one decade, many parts of Southeast Asia 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 over-exploitation of water resources have depleted aquifers, lowered water tables, shrunk inland lakes, and diminished stream flows, some to the 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 percent), followed by Vietnam (19.5 percent) in South-East Asian region. This indicates the higher vulnerability of Thailand and Vietnam to changes in water resources. In Thailand 95 percent of the total fresh water withdrawal is used for agricultural production, whereas it is only 68 percent 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, 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 which 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 is 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 perspectives 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 Third Assessment Report particularly identified the Asian region as most vulnerable to climate change related impacts due to its poor adaptive human systems (Lal et al., 2001).

Climate change trends and projections for 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 2 shows the climate projections for central and south Asia. A general warming is expected with a 100 percent 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 (Sivakumar et al., 2005).

Table 2. Climate projections for different dryland regions of Asia

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) in Kao (2009)

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

Table 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. Climate change: Trends and projections

Country	Major trends and projections of climate change		
China	Annual average air temperature has increased by 0 5~0 8°C during the past 100 years (NDRC, 2007)	The annual precipitation decreased gradually since 1950s with an average rate of 2 9 mm/10 years (NDRC, 2007)	Annual mean air temperature would increase by 1 3~2 1°C in 2020 and 2 3~3 3°C in 2050 Precipitation would possibly increase with a projected increase of 2~3% by 2020 and 5~7% by 2050(NDRC, 2007)
India	Warming trend in India is about 0 57 °C per 100 years (Sivakumar *et al*, 2005)	Increase in winter temperature will be 1-4°C Average temperature increase will be 2 33 to 4 78°C with double CO_2 (Mall et al, 2006 in Mitra et al, 2008)	Predicted 20 % increase in rainfall 7- 10 % increase in annual mean precipitation and decline and 10-15 % increase in monsoon rainfall (Mall et al, 2006 in Mitra et al, 2008)
Pakistan	Mean annual temperature has increased by an average rate of 0 08°C per decade Mean annual rainfall has not changed with any discernible trend since 1960 (Mc Sweeney et al, 2009)	Mean annual temperature is projected to increase by 1 4 to 3 7°C by the 2060 Rainfall changes range from -9 to +20mm per month (-20 to +41%) by the 2090s, (McSweeney et al, 2009)	A 3 to 5°C overall increase in temperature over the next century The southern regions will have increased rainfall (up to 20 percent), the northern regions will have decreased rainfall (5%) (various sources, in ISET,2008)

Bangladesh	Average temperature shows an increasing trend of about 1°C in May and 0.5°C in November during 1985 to 1998. Annual mean rainfall exhibits increasing trends. (Bangladesh,2007).	Temperature would rise 1.3°C by 2030 (over mid-20th century levels) and 2.6°C by 2070 (Ahmed and Alam, 1999 in Agrawala, 2003).	GCM estimated 1, 1.4 and 2.4 °C increase in annual temperature by 2030, 2050 and 2100 respectively. Precipitation will likely to increase during the summer monsoon (Agrawala,2003).
Sri Lanka	During 1869-1993, increasing trend of about 0.30 °C per 100 years (Sivakumar *et al*, 2005).	Warming trend is accompanied by increases in diurnality. (Sivakumar *et al*, 2005).	Two-fold CO2 level would lead to an estimated 1.4-2.7° C increase in the average temperature.(http://sgp.undp.org/downloads/2002-3.pdf).
Thailand	A long-term decreasing trend in rainfall (Sivakumar *et al*, 2005). An increase from 0.10–0.18°C per decade over 5 decades. (Boonprakrob, 2006 and ADB REPORT, 2009).	Temperature increase would be 2--4°C by the end of this century (TEI 2000 in ADB REPORT, 2009). Rain fall amount changes spatially (GCM) (Boonprakrob, 2006).	Rainfall in the northeast would be constant while it would increase by 40% in the south and in other parts would increase by 20% (Boonprakrob, 2006).
Vietnam	During 1895-1996, the mean warming trend is estimated at 0.32 °C over the past 3 decades (Sivakumar *et al*, 2005). Summers have become hotter, with average monthly temperatures increasing 0.1–0.3°C per decade (ADB REPORT, 2009).	Annual average temperature increased 0.1°C per decade and 0.7°C, or 0.14°C per decade, during 1951- 2000 (ADB REPORT, 2009). Average monthly rainfall decreased during July and August (Cuong 2008 in ADB REPORT, 2009.	An increase in temperature would be of 2--4°C by 2100. Annual rainfall in most areas would increase by 5–10% toward the end of this century (Cuong 2008 in ADB REPORT, 2009).

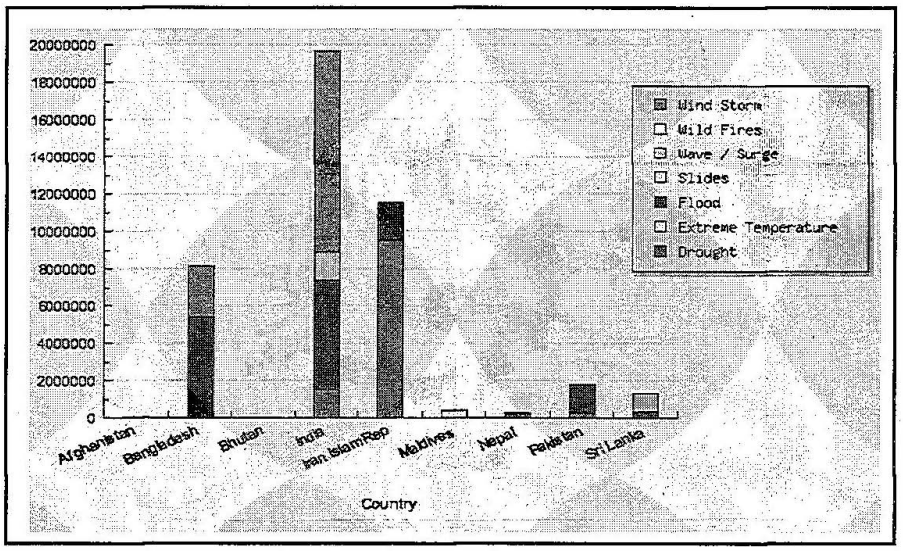
Natural disasters and extreme events in Asia

The Third Assessment Report 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, 2007-08).

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

At the same time, drier summer conditions in arid and semi-arid areas will lead to more severe droughts. India and Pakistan mainly depend on cultivation in arid and semi-arid lands for their cultivation and already experience frequent natural disasters

(HDR, 2007-08). The amount of annual rainfall varies dramatically in drylands. Given the relatively scant seasonal and inter-annual precipitation, a certain level of rainfall deficiency can easily give rise to the occurrence of drought. In addition, a large diurnal temperature range (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) have reported an increase in frequency and severity of wild fires in grassland and rangelands in arid and semi-arid Asia in recent decades. Figure 4 shows the damages due to extreme climate events in Asia.



Source: OFDA-CRED (2005) in HDR, 2007-08
Figure 4. Damages due to extreme climate events in Asia

Table 4. Climate variability and extreme events: Trends and projections

Country	Trends and projections of climate variability and extreme events		
China	Drought in northern and N-E china and 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).	Arid area would probably become larger and the risk of desertification and retreat and disappear of glacier might increase. (NDRC, 2007).
India	Increase in extreme rainfall events over NW India during the summer monsoon. Higher frequent drought following the occurrence of ENSO and 50% of Indian monsoon failures occurrences since 1871 during El Nino years.	No identifiable variability in number, frequency or intensity of tropical cyclones in northern Indian Ocean region over 100 years (Sivakumar *et al.*, 2005). Number of storms with more than 100 mm rainfall in a day is increased by 10%	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).

	(Sivakumar *et al.*, 2005). 22 major drought years during 1871-2002 (Prabhakar and Shaw, 2008).	per decade (UNEP 2007 in HDR, 2007/08).	
Pakistan	Average number of 'hot' days and nights[1] 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).	Annually, 'hot' days will occur on 16-25% and 18-38% of day by the 2060s and 2090s respectively. All projections indicate decreases in the frequency of days and nights that are considered 'cold' in current climate (Mc Sweeney *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 towards 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).	2^0C warming with 10% increase in precipitation would increase runoff in the major rivers significantly. Mirza and Dixit (1997 in Agrawala *et al.* 2003).
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.	Predict increase in frequent and prolonged droughts, thunderstorms and sea water level.
Thailand	During 1990 and 1993 the rainfall was below normal, 1994-1995 were flood years and 11m people in were affected by water shortages in 1997, over 10m people in the agricultural region affected by drought in 2008. (Kisner, 2008).	Frequency of extreme events includes prolonged flood and drought, landslides, and strong storm surges increased. (Jesdapipat 2008 in ADB REPORT, 2009).	An increase in coastal erosion is expected (ADB REPORT, 2009).
Vietnam	There were higher frequency droughts following the occurrence of ENSO and Increased occurrence of extreme rains causing flash floods. (Sivakumar et al., 2005, ADB REPORT, 2009).	Rainfall intensity, more frequency 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.	It is predicted that a one-meter rise in sea level could lead to flooding of 5,000 sq km of Red River Delta and 15,000-20,000 sq km of Mekong Delta (ADB REPORT, 2009)

[1] 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

Impacts of climate change on agricultural production in Asia

Agriculture in SAT is under inherent climatic and non-climatic stresses and has evolved under the influence of different constraints arising out of these stresses. Limited fresh water availability, seasonal variations 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).

The issue of climate change in agriculture in the SAT regions is always complex due to the presence of numerous non-climatic stresses which lead to constraints and uncertainties, threatening people's livelihoods and sustainability of food production across the region.

There are caucuses among the 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 percent by 2050 if no action is taken to combat the effects of increasing temperatures and hydrologic disruption (IPCC, 2007). Since temperatures in the South Asian continent are already reaching critical levels during the pre-monsoon season, further increase would reduce significantly the yields of all crops including rice (Wassmann and Dobermann, 2007).

Sivakumar et al. (2000) summarise that climate variability has been, and continues to be, the principal source of fluctuations in global food production, particularly in the SAT regions. Data show that the dry tropics, where rainfed agriculture provides 60 percent of the world's food, will be the most vulnerable to climate change. ICRISAT data show 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 5. Agriculture impacts due to climate change: Trends and projections

Country	Trends and projections of agriculture impacts due to climate change		
China	2-4 day advancement of spring phenophase since 1980's (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 ^{0}C, yield loss for rice & wheat would be between 32 and 40 % For 4 9 ^{0}C yield losses between 41 & 52%	Wheat yields in central India may drop by 2% in a pessimistic climate change scenario (GoI, 2004 in HDR 2007-08)	2 ^{0}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 2007-08)

Pakistan	Wheat yields are predicted to decline by 6-9% in sub-humid, semiarid and arid area with 1^{0}C increase in temperature (Sultana and Ali 2006 in HDR, 2007-08).	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 -08).	A 0.3 ^{0}C decadal rise could have a severe impact on important cash crops like cotton, mango and sugarcane (MoE 2003 in HDR, 2007-08).
Bangladesh	Drought affects annually about 2.32 mha and 1.2 mha in kharif and Rabi seasons respectively (Bangladesh,2007).	Rice and wheat production might drop by 8 and 32 % respectively by 2050 due to temperature rise (IPCC in Bangladesh, 2007).	A net negative effect on the yields of rice (Karim et al 1996) in HDR 2007-08).
Srilanka	0.5 ^{0}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, 2007-08).	In warm, semi-arid 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, 2007-08).
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. Salt water 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 salt water 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.

Adaptation to Climate Change

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

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).

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 improved crop varieties that are resistant to flood, heat and drought. 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.

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

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

Mainstreaming the adaptation strategy in development planning in Asia

There is initiation of national-level adaptation efforts to climate change in the Asian countries. Several least-developed countries in the Asia and Pacific regions have prepared National Adaptation Program for Action (NAPAs), and in India and the People's Republic of China are undertaking activities in both adaptation research and policy. Non-governmental organizations (NGOs) and research institutes are also aligning their activities towards climate adaptation.

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 these incorporate 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, benets 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 the selected countries:

China

China established the National Coordination Committee on Climate Change (NCCCC), which presently comprises 17 ministries and agencies. The NCCCC has made significant contribution to the formulation and coordination of China's important climate change related policies and measures, providing guidance for response of central and local governments to climate change.

In 2006, China published its National Climate Change Program for adaptation to climate change, 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 Programme are high-efficiency water-saving agro-technologies such as spray and drip irrigation, high-efficiency flood-control, agro-biology, agricultural breeding , new-type fertilizers, disease and pest control, and technology for observation and pre-warning 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. Also, strategies have been identified for drought vulnerability reduction such as changes in land-use pattern, water conservation, flood warning systems, and crop insurance (TERI, 2001). Ongoing programs such as watershed development, command area development, 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 and Shaw, 2009).

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

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

(i) Enhancement of the local capacity for drought preparedness and mitigation (capacities of communities and local governments),

(ii) Improvement in drought prediction and communication (clarity in centre-state relationships in dealing with the natural hazards such as droughts),

(iii) Improvement in drought monitoring, and

(iv) Enhanced operational preparedness for initiating quick response.

Pakistan

National policies which consider climate change adaptation in their implementation are: (i) National Environment Policy (2005); (ii) National Sanitation Policy (2006), and (iii) National Energy Conservations Policy (2006). Pakistan has established a Global Change Impact Studies Centre (GCISC), Prime Minister's Committee on Climate Change, a National Disaster Management Authority, National Implementation Committee for NEP, and at the top of all these is the Pakistan Environmental Protection Council (PEPC) as various national initiatives.

Pakistan views the 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 has been established by UNDP. The organizations responsible for disaster management are National Disaster Management Authority, The Federal Flood Commission (FFC), Emergency Relief Cell (ERC) and Pakistan Meteorological Department (Kundi, 2008).

Bangladesh

Bangladesh submitted its National Adaptation Programmes 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 Programme (CDMP) 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 which 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 agro-ecosystem.
- Adaptation to agriculture systems in areas prone to enhanced flash flooding – North East and Central Regions 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).

Sri Lanka

Sri Lanka was the first country in Asia to prepare a National Environmental Action Plan (NEAP) in 1992, which was published with further updates in 1998 and 2003. Priority environmental issues from the poverty perspective were identified. Sri Lanka's Poverty Reduction Strategy in March 2003 was considered to be reasonably successful by the World Bank's environment department in mainstreaming the 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, 2001).

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

Thailand

In Thailand, the Ministry of Natural Resources and Environment 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 (NCCC), chaired by the Prime Minister. Technical sub-committees have also been established under the national committee to support different aspects of climate change issues, including mitigation and 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).

The National Climate Change Adaptation Plans and implementation in Thailand for agricultural sector includes germplasm banks for major crops, increased use of degraded land for flood control, specific policy on food security, improved water efficiency in cropping and appropriate use of land, experiment crops in marginal land

areas, financial and technological support to local communities for adaptation and forest-set aside program ONEP (ADB, 2009).

Vietnam

Ministry of Natural Resources and Environment (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 Programme) is officially described as the main framework for the management and coordination of the activities. National strategies are designed to reduce the risk of disasters and the key institution is the Central Committee for Flood and Storm Control (CCFSC).

Climate change adaptation projects are particularly emerging in the Central Coastal 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 the Asian countries have started their adaptation planning at national level, still they need to act at a faster pace for a tangible 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 are hindering the process in these developing countries.

Farm level adaptation to climate change

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

Kelly and Adger (2000) have argued that rather than synthetically identifying several regions and sectors as vulnerable, proposing 'new' ways to adopt 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, is more important. This implies that indigenous technologies and agrarian practices can be supported to enhance the adaptation strategies. This can be done through identifying the historically developed traditional 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 climatic events.

Research effort should be seen as complementing the above 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, climate change adaptation at different levels needs to be provided with technological, institutional and policy support from different sources, viz. government, NGOs, local institutions, community groups or societies and also international cooperation between different regions in order to strengthen and improve the adaptive capacity of farmers.

Conclusions

Research on long-term climate change was the major issue focused in the early studies on climate change. Recently, the studies on climate variability have attained a significant attention from the researchers. Hence, the paper reviewed the studies on both the long-term changes and short-term variability in climate.

The discussion in this paper implies that countries, particularly in SAT region, are vulnerable to the current climate situations and climatic shocks in future. Thus, understanding the nature and degree of vulnerability is initial concern of any climate change study to build adaptation strategies based on the understanding of ground level strategies to cope with the current climatic situation. Further, the paper focussed at drawing the attention to the following three major issues:

1. The first aim of research endeavor is to understand the climate change context (both socio-economic and environmental (bio-physical), which decides the vulnerability of the region. This provides a systematic investigation on the argument that degree of climate change vulnerability to depends on socio-economic, 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 in an integrated way.

2. The next step entails linking changes in climate including its variability and the changes in different aspects such as cropping pattern, income and employment status and gender 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 socio-economic development status of a region as part of poverty reduction.

3. Another major focus is recognizing the past and current adaptation strategies used of 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.

Hence, this is a comprehensive effort to understand and analyze the vulnerability and impacts of climate change and the adaptation strategies of farmers. It is envisaged

that the above issues centric to the agenda of climate change challenges in SAT regions of Asia will be addressed well so as provide to suggestions on the strategies and policies to reduce the vulnerability.

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