An assessment of climate change impacts and adaptation in South Asian agriculture

Sonam Wangyel Wang
Division of Environmental Science and Ecological Engineering, College of Life Sciences, Korea University, Seoul, Republic of Korea and Bhutan Institute of Himalayan Studies, Thimphu, Bhutan, and

Woo-Kyun Lee and Yowhan Son
Division of Environmental Science and Ecological Engineering, College of Life Sciences, Korea University, Seoul, Republic of Korea

Received 26 May 2016
Revised 13 October 2016
10 February 2017
24 March 2017
Accepted 4 May 2017

Abstract

Purpose – The purpose of this study is to synthesize the impacts of climate change on agriculture and assess the status of policies, programs and strategies to adapt small farm holders to climate change in South Asia.

Design/methodology/approach – The authors collected secondary information through a desktop review of policy documents, action plans and published reports. Face-to-face interviews with policy makers, agriculture and climate experts representing the government, non-governmental organizations, international development agencies and the private sector were also conducted to validate the secondary information.

Findings – The results revealed that agriculture is the dominant economic mainstay providing livelihood to over 70 per cent, employing 60 per cent of the labor force and contributing about 22 per cent of the regional gross domestic product. Climate impacts, such as floods, sea level rise and salt intrusion, increased frequency and intensity of storms, and pests combined with increasing water scarcity continue to reduce arable land, reduce yield of crops and threaten the food security of farmers. Adaptation efforts include using improved varieties of crop; changing cropping patterns and planting seasons; and water conservation techniques. However, progress remains low because of a lack of adequate technical knowledge and financial resources.

Originality/value – The amount of published literature on climate change and its impact on agriculture is increasing, but there is little effort to analyze and document impacts and strategies to adapt small farm holders to climate change at a landscape level, particularly in South Asia. This study fills in this gap and will serve as a valuable source of information for those wishing to conduct research or develop adaptation strategies for any of the four countries of Bangladesh, Bhutan, India and Nepal.

Keywords Agriculture, Adaptation, Climate change, Mitigation, Food security

Paper type Research paper

1. Introduction

South Asia is home to over 1.3 billion people of diverse ethnicity who speak over 1,000 different languages and dialects. The region is also endowed with rich natural resources and contains global biodiversity hotspots providing various ecosystem services, including water, biodiversity, soils, natural beauty, recreational opportunities and wilderness – all of which sustain the livelihood and economy of the vast population (Tiwari and Joshi, 2014). The Indo-Gangetic Plain (IGP), Indus delta and Bangladesh flood plains are historically unique systems of global importance that have produced food and been the backbone of cultural and economic development in the region for centuries. The region is also referred to as the “third Pole” and the water tower of Asia, as it stores a large volume of water in the

International Journal of Climate Change Strategies and Management
Vol. 9 No. 4, 2017
pp. 517-534

1756-8692
DOI 10.1108/IJCCSM-05-2016-0069

form of ice and snow and regulates the flow of 10 major river systems in the region (Morton, 2011).

For a large majority of the population (two-third of the total population) consisting predominantly of the rural poor, subsistence agriculture constitutes the main source of livelihood and food. Agriculture is heavily dependent on natural resources, particularly forest and pastures, as they constitute the source of biomass energy (FAO, 2010; Singh *et al.*, 1984). Agriculture is also the largest source of employment and the single largest contributor to the gross domestic product (GDP) of the region. However, what seems to be a sustainable traditional resource use structure is quickly emerging to compete for limited resources with nature to respond to growing population pressure and the resultant increased demand for natural resources, such as arable land, grazing areas, fodder and fuel wood (ICIMOD, 2010). These pressures are further exacerbated by national economic developmental plans in South Asia, which are mainly focused on increasing agricultural productivity, improving market access to alleviate poverty and enhancing economic development. These emerging developments have led to the depletion of critical natural resources, impacting the natural environment and basic ecosystems services. This is particularly the case for increased incidences of water shortage from the drying of water sources and the increasing vulnerabilities of rural communities, particularly the poor and the groups vulnerable to food and livelihood security (Jandl *et al.*, 2009). In these scenarios, achieving food security, economic development and biodiversity goals seems a distant dream, particularly with the additional challenges presented by global climate change.

For instance, global climate change is estimated to reduce Bangladesh's GDP by 29,925 million Takas (−0.11 per cent) by 2030, with agricultural output falling by −1.23 per cent accompanied with a 1.52 per cent increase in food imports. The forecast for other South Asian countries is no better than that for Bangladesh (Banerjee *et al.*, 2015). South Asia, though not a significant contributor of greenhouse gases (GHGs), bears a disproportionate brunt of the climate change impacts ranging from floods caused by glacier lake outburst floods (GLOFs), rising sea level, salinity, water scarcity and extreme weather events. These impacts are further exacerbated by: extreme poverty, weak resilience of the people and their livelihood systems to the impacts of climate change, and lack of technical knowledge and the necessary funds to adapt to climate change impacts (Schild, 2008).

South Asian nations and their governments recognize the importance of addressing climate change if they are to achieve their economic development goals and have thus formulated policies targeted at enhancing adaptation and reducing GHG emissions. From the adaptation and mitigation programs and projects, it is clear that the South Asian nations are serious in their efforts to address climate change issues and integrate them into their economic and social development plans. Consequently, South Asian nations have taken an active role in the international crusade for fighting climate change. This is occurring particularly in the United Nations Framework Convention on Climate Change (UNFCCC) process and in the process of developing national policies on the clean development mechanism (CDM) issues.

South Asian Governments and their development partners have invested significant portions of their lean financial budgets, time and effort in formulating climate policies, strategies, and action plans and implementing numerous adaptation and mitigation projects to enhance the capacity of small farm holders to contain climate impacts and reduce GHG emission. However, there have been few attempts to either assess the status of policies, projects and other efforts or to identify gaps and needs for guiding future policies and projects.

Our study attempts to fill in this current gap by assessing the current status and trends of projects, policies and other efforts at the regional level in South Asia to:

- highlight the impacts of climate change and implications for agriculture;
- assess policies and strategies for adaptation and mitigation, and
- identify existing gaps and future needs for capacity building, research and governance.

2. Approaches and methodology

Our general approach to the study was to synthesize available policy, program, project and other literature on the impacts, adaptation, mitigation and vulnerability of agriculture to climate change in the South Asian nations of Bangladesh, Bhutan, Nepal and India (Figure 1). Our study used a mixed method to integrate information collected from a desktop review of the existing literature and government documents relating to climate change adaptation and consultation with relevant stakeholders in each country. Information collection through desktop review and consultative meetings/interviews was then synthesized into this paper.

2.1 Desktop review

Available literature including peer-reviewed journal articles, unpublished articles, government reports, project reports, policies, acts and rules relating to climate change, agriculture and food security was reviewed and analyzed for each of the four countries.

2.2 Consultative meetings and interviews

Consultative meetings and interviews were held with national focal persons for climate change, agriculture and food security in each of the four countries. In addition, consultative interviews and meetings were held with climate change and agriculture experts from

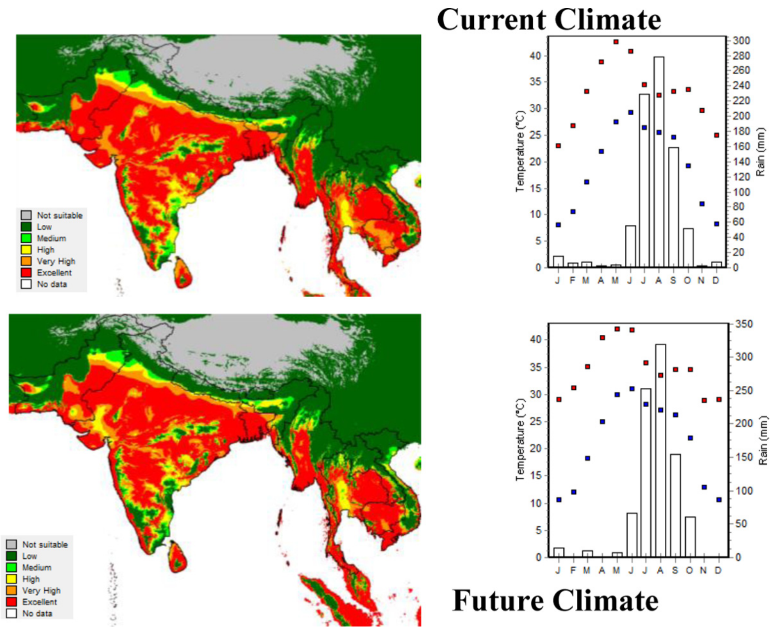

Figure 1.
Map showing temperature and rain projections in South Asia up to 2060

relevant government agencies, autonomous agencies, non-government sectors and the private sector, including financial institutions, in each of the four countries.

3. Findings

3.1 Impacts of climate change and implications for agriculture and food security

3.1.1 Climate change trends, projections, sensitivities and impacts. The South Asian region is highly sensitive to the consequences of climate because of its topography and altitudinal variations from the highest mountains in the Himalayas to the coastal areas bordering the Indian Ocean (Government of India, 2015). It is known to be the most disaster-prone region in the world, supporting a huge population of more than 1.3 billion people (UNEP, 2003). The future predictions for the region highlight increased frequency and intensity of extreme weather events, such as droughts and floods (IPCC, 2001) that could expose this huge population to natural disasters. An analysis of rainfall data for India, for instance, highlighted not only an increased frequency of severe thunderstorms over the past 50 years but also a 10 per cent increase per decade in rainstorms with more than 100 mm of rainfall in a day (UNEP, 2007). These events when spread over a few days are likely to impact water recharge rates and soil moisture conditions, which impact agriculture and food security. In contrast, some parts of Asia have experienced prolonged drought with many countries in the region facing acute water shortages. Kelkar and Bhadwal (2007) estimate that in South Asia alone, 2.5 billion people will be affected by water stress and scarcity by the year 2050.

A trend analysis of the observed data on climate confirms that there is a rising trend of temperature in South Asia (Figure 1). Temperatures are expected to increase between 2.5 and 5°C in the Indian Sub-Continent by 2060, with mean precipitation decreasing over time. Trends of monsoon onset and withdrawal from 21 years of data show that the monsoon season is elongating at both the ends. Onset will occur earlier by 71 per cent of a day per annum, and withdrawal will retreat by about 15 per cent of a day per annum. Although this trend appears to be elongating the monsoon period, it is not likely to happen because of the changes of seasons. In the case of trends of withdrawal of monsoon, they are not notably distinct, whereas the trend of monsoon onset is quite distinct.

Doubling of carbon dioxide (CO_2) will have more of a positive impact on major crops, but the simultaneous rise of temperature will adversely affect warmer environment crops and C4 crops. Response to a temperature rise is more negative in maize than in wheat and rice (Timsina *et al.*, 2010; Ortiz *et al.*, 2008). The yield reduction will be severe for all crops at a 4° C temperature rise. However, the potential yield reduction below the ambient at 4°C will vary from 25 to 33 per cent in the Terai, 11.3 to 21.1 per cent in the hill areas, and 3 to 12.7 per cent in the mountains. Hence, mountain environments will be more favorable than the tropical flat land to cope with the climate change phenomena.

Anthropogenic emission of GHGs has been mainly responsible for increasing the rate at which the earth is warming. While it is encouraging to see an increasing number of high-profile efforts to reduce GHG emissions by some of the industrialized countries, such as the recent ratification of the Paris Agreement, US-China Joint announcement on climate change (November 12 2014, Beijing, China) and the EU's team efforts to reduce aviation emissions, little has been realized in terms of actual reductions in the amount of GHGs emitted. With the industrialized world showing few signs of slowing down their emissions and the developing world following their models, GHG emissions are expected to increase. This presents a notable challenge for meeting the 2°C goal set by the IPCC. India's emissions increased by 65 per cent between 1990 and 2005 and are projected to increase by 47 per cent between 2011 and 2020 (Rastogi, 2011; IEA, 2007). Temperatures in India are expected to increase between 2.5°C and 5°C by 2060, resulting in yield losses of many crops (Kumar and

Parikh, 2001). In this scenario, any increased frequency of extreme events, such as droughts, floods or cyclones, from a changing climate will cause significant loss of property and lives, with the poor being more at risk. The impact will be felt across the country but more severely, in the glacier-fed IGP.

The impacts of climate change on sectors such as agriculture, water resources and health presents the South Asian governments and their development partners with formidable challenges to reduce poverty and achieve their sustainable development goals (Table I).

3.1.2 Agriculture and food security. Agriculture is the mainstay of South Asian economies employing the largest number of people and contributing significantly to the GDP in the region (Table II). With three-fifth of the cropped area depending on rainfall for irrigation, the success of South Asian economies hangs by the delicate balance between water availability and access to it at the right time. With a 20 per cent contribution to the country's GDP, agriculture in Bangladesh employs 48 per cent of the labor force (Mainuddin *et al.*, 2011). Serving as major livelihood resources, the agricultural sector plays a critical role in defining poverty levels in Bangladesh. Agricultural sectors are also the largest consumer of water in South Asia with India alone using 85 per cent of its water for irrigation purposes.

Global warming will negatively impact rice and wheat yields in South Asia with small holders being more at risk because of low financial and technical capacity to adapt to climate variability and change (Pathak *et al.*, 2003). The World Bank (2010) predicts that the Bangladesh national rice production will decline because of climate change and the annual growth rate will reduce from 2.9 to 2.55 per cent in the average climate change scenarios during the period 2005-2050. Similarly, wheat yields are expected to decline sharply because of climate-related stresses. IPCC estimates that by 2050, rice production in Bangladesh will decline by 8 per cent and wheat by 32 per cent. With 32 per cent of the country's area susceptible to loss from inundation by the rising sea level and salinity, Bangladesh's ability to produce food will sharply decline with global warming. In India, wheat yields would drop by at least 2 per cent in a pessimistic climate change scenario (Government of India, 2004). Kumar and Parikh (2001) showed that a 2°C rise in mean temperature coupled with a 7 per cent increase in mean precipitation will reduce net revenues by 8.4 per cent. Coastal areas of India are also highly susceptible to the sea level rise and other weather-related disasters such as tropical cyclones and storms.

More than half of the population in Bhutan and Nepal depends on agriculture, which is facing increased frequency of droughts, floods, wind and hail storms, and pests (Government of Bhutan, 2012; Government of Nepal, 2011; 2004; ICIMOD, 2010). The steep terrain further exacerbates the sensitivity of agricultural land in Bhutan and Nepal to climate fluctuations, which can easily cause micro-climatic zones to either shift towards unsuitable steeper slopes or just disappear altogether. Increased flooding, droughts, pests and diseases, and loss of land to landslides associated with climate change directly hamper crop production (ICIMOD, 2010). Studies by ICIMOD (2010) also reported that increased temperature, higher evapo-transpiration rates and intense erosion could deteriorate soil fertility. Such loss of productivity can translate into intensified risks of food insecurity. In the current climate change scenario, food security cannot be achieved without enhancing livelihood options, which cannot happen without conservation of productive resources, such as water, land, forests, rangelands, biodiversity and the natural environment along with enhanced access and optimized utilization.

3.1.3 Water/glaciers. Water is a critical resource for all livings things to survive on this earth. Unfortunately, it is also a sector that is directly threatened by global warming and climate change. The Himalayan range contains high-altitude glaciers and is the water tower of Asia, supplying water to thousands of rivers on which more than half of the world

Country	Vulnerability to climate change
Bangladesh	*Agriculture* Bangladeshi agriculture and livelihoods are highly vulnerable to sea level rise, salinity intrusion and river flooding during heavy rains. Impacts include saline water intrusion, drainage congestion and inundation of coastal area, changing its ecology and thereby altering agricultural practices and affecting millions of farmers (Islam *et al.*, 2015; Paul and Rashid, 1993). Few crop species including traditional rice species have already become extinct. The estimated impacts on rice yield vary between -6% and +14% depending on different climate change scenarios *Water Resources* Bangladesh, although surrounded by water with several major rivers emptying into the Bay of Bengal, faces the challenge that its agriculture is highly vulnerable to water scarcity. Sea water is salty and its intrusion disseminates life, taking away farmland and property from farmers who become refugees in other areas including Dhaka city. Bangladeshi agriculture is also constantly impacted by river floods due to either heavy incessant rain or landslide lake floods or glacier lake outburst floods (GLOFS) upstream. Water-related impacts of climate change are likely to be felt mostly by coastal areas and river flooding
Bhutan	*Agriculture* Bhutan agriculture is highly vulnerable to climate change. A slight change in temperature could shift agricultural zones. Climate change has rendered uncertainties with rainfall predictions, thereby confusing farmers about planting seasons. In recent years, Bhutan's agriculture is facing too much rain when not required and no rain when required. Monsoonal rain/hailstorms continue to destroy crops, costing farmers and government millions (NEC, 2006) *Water resources* Water availability in Bhutan is controlled by rainfall, glacier and snowmelt; land use practices and user demands. Hydropower generation and agriculture, Bhutan's major economic mainstays, are being impacted by a combination of reduced average flow of snow-fed rivers in winter and an increase in peak flows and sediment yield. Summer flooding and rainstorms also increase run-off, enhance soil erosion and accelerate sedimentation in the existing water supplies
Nepal	*Agriculture* Massive deforestation, degradation of forest quality coupled with monsoonal rain/hail storms, flooding and soil loss cause agriculture crops to fail. Rising temperatures adversely affect wheat and maize yields *Water Resources* Retreating glaciers and changes in seasonal snow fall and melt will lead to greater uncertainty about water flow and availability in Nepal. Nepal also faces flooding threats due to GLOFS. With only 17% of the land being irrigated, Nepal's rain-dependent agriculture will be highly impacted by erratic rainfalls (Tiwari and Joshi, 2014)
India	*Agriculture* Climate change is predicted to decrease wheat yields in central India by 2% in a pessimistic climate change scenario (GoI, 2004). A temperature rise of 1.5°C and a 2-mm increase in precipitation could result in a decline in rice yields by 3 per cent to 15 per cent (TERI, 2010). Sorghum yields would be affected, and yields are predicted to vary from +18 per cent to -22 per cent, depending on a rise of 2 to 4°C in temperatures and increase by 20 per cent to 40 per cent of precipitation (IPCC, 2001) *Water resources* India is already water starved, and climate change impacts continue to worsen the situation. Glacier melt in the Himalayas affects Indus, Ganga and Brahmaputra river basins with summer flooding and winter droughts According to United Nations projections, India is estimated to experience water stress by 2025 and is likely to cross the "water scarce" benchmark by the year 2050 in the high-growth scenario. Water stress and scarcity are defined as situations where the per capita annual water availability is less than 1700 m^3 and 1000 m^3, respectively (World Bank, 2010)

Table I.
Overview of climate change vulnerability and impacts in South Asian nations

population depends. Accelerated melting of glaciers would lead to filling glacial lakes beyond their capacities or formation of new lakes, resulting in increased flows and causing GLOFs during monsoon followed by water scarcity in winter seasons. The overall flow will decline over a long period with potentials for prolonged drought in some of these currently fertile valleys. This will have huge ramifications for those depending on water, particularly for agricultural, industrial and hydropower generation purposes. According to the IPCC (2001), by 2050, the annual runoff in the Brahmaputra and the Indus is projected to decrease by 14 and 27 per cent, respectively, thereby greatly reducing the water availability for various purposes for people living downstream (Uphoff, 2006). Bangladesh is perhaps the most at risk from flooding, increased salinity and loss of land and drainage congestion because of a sea level rise and reduction of dry season trans-boundary flows. Such events will result in an increase in irrigation water requirements and other potential impacts, such as higher frequency of tropical cyclones and a rise in storm surge depths. Studies in Bangladesh (Opu *et al.*, 2014) reported that severe floods, which cause extensive damage to crops and property, occur at intervals of 7-10 years, while catastrophic floods occur at intervals of 2-50 years, which greatly annihilates any socioeconomic developments made at that point. In Bhutan and Nepal, availability of water for domestic and agricultural use is heavily dependent on heavy rainfall, glaciers or snow. A reduction in average flows of snow-fed rivers, coupled with increased peak flows and sediment yield would have a major impact on hydropower generation, urban water supply and agriculture.

Changes in the hydrological cycle, depletion of water resources and receding coastal areas with increased salinity are some of the top environmental challenges facing South Asia in the context of global warming. It is estimated that a temperature rise of 4°C can result in the loss of 70 per cent of snow and glacier areas from snow and ice melting with significant extents of coastal areas being submerged. Glacier melt water will contribute to a faster development of glacier lakes, and this will lead to increased potential for glacier lake out-burst flood hazards. Catastrophic flooding is already taking place in South Asia because of glacier melt, and people are living in constant fear of when the next GLOF may occur. ICIMOD has identified over 200 glacier lakes that risk bursting. A particular concern regarding these lakes is that there are no data available regarding when they will burst, making life very uncertain downstream.

3.1.4 Coastal and mountainous areas. High-altitude mountains (particularly above the tree line) and coastal areas mimic each other in many respects and will bear the brunt of climate change impacts. High-altitude areas in South Asia, particularly the Hindu-Kush Himalayas, cover an area of 4.3 million km^2 and serve as the primary source of water for South Asia (ICIMOD, 2010). The mountains are also home to over 200 million people of diverse socioeconomic backgrounds. Rising temperatures in these fragile mountains can tip the natural balance, sparking off severe natural disasters. The latter include GLOFs, flash floods, wind/snow storms and the associated soil erosion, landslides and earth slips, thereby significantly impairing peoples' abilities to make a living and adapting to climate change impacts. Further, these events lead to erosion of millions of tons of silt, which ends up in the

Table II. Gross domestic product (GDP) of South Asia and agricultural contribution

	Bangladesh	Bhutan	Nepal	India
GDP growth (1990-2000)	6.0	6.1	4.9	6
Agriculture (1990-2000)	2.9	3.2	2.5	3.8

river valleys and coastal areas, causing losses to agricultural land and clogging irrigation canals and hydropower dams. The coastal areas as we have seen are at great risk from sea level rise and surge storms. Major cities at risk include Dhaka, Chennai and Mumbai with high population densities and heavy infrastructures. For example, in 2005, Mumbai suffered its worst flood due to record-level precipitation within 24 h, killing over 1,400 people, destroying 14,000 homes and stalling human activities, communication networks and public transportation, with an estimated loss of 90bn Indian Rupees (Ravindran, 2014). On the other hand, from 1984 to 2007, Bangladesh suffered a total loss of US$14.979bn from floods and the resulting inundation and damages to crops and property (Government of Bangladesh, 2009). Tropical cyclones, rising salinity, droughts and health-related problems further exacerbate climate impacts, particularly in the agricultural sector, threatening food security and putting the livelihoods of over 60 per cent of Bangladeshi people in danger.

3.1.5 Greenhouse gas emission. The current GHG inventory for South Asia shows gross CO_2 emissions at 865,845.63 Gg, CH_4 at 20,241.55 Gg and N_2O at 225.51 Gg (Table III). The total CH_4 emissions were estimated at 20,240.28 Gg with rice cultivation and livestock as the main sources. In the present scenario, this emission is expected to increase with increased emissions from industries, anthropogenic emissions, deforestation and lack of innovative approaches to mitigation. For instance, India's emissions are projected to increase by 47 per cent between 2011 and 2020 (Rastogi, 2011; IEA, 2007); similarly, emissions from Bangladesh (Government of Bangladesh, 2015) and Nepal are projected to increase as these countries become more industrialized and more populated. This will put more pressure on natural resources and exacerbate climate (Government of Nepal, 2016). The one exception is Bhutan, which is taking responsibility for its emissions and is the first carbon-neutral country in the world. The general perception that global warming is a responsibility of the industrialized nations needs to change to one where every individual, community, nation and region takes voluntary actions to reduce its carbon footprint.

3.2 Responding to climate change impacts

Besides the political and economic debates at the international forums, responses to climate change are challenged by existing perceptions among citizens around the world. One such view is that climate change mitigation is the responsibility of the industrialized nations and that they were responsible for it in the first place. Second is the situation where climate

Country	GHGs	Agri	LULUCF	Others*	Total	Net
Bangladesh	CO_2	0	7,837.97	16,459.72	24,297.69	24,297.69
	CH_4	1,127.73	0	63.22	1,190.95	1,190.95
	N_2O	14.32	0	0.06	14.38	14.38
	CO_2	0	−3,549.52	228.46	−3,321.06	−3,321.06
Bhutan	CH_4	19.17	0	0.16	19.33	19.33
	N_2O	2.13	0	0	2.13	2.13
	CO_2	0	8117.00	1,630.00	9,747.00	9,747.00
Nepal	CH_4	867.00	0	81.00	948.00	948.00
	N_2O	29.09	0	2.00	31.09	31.09
	CO_2	0	14,142.00	782,721.00	796,863.00	796,863.00
India	CH_4	14,175.00	6.5	3,901.00	18,082.5	18,082.5
	N_2O	151.00	0.04	27.40	178.44	178.44
Total		16,385.44	26,553.99	805,114.02	848,053.45	848,053.45

Note: *Others include emissions from energy and industry

Table III. Greenhouse gas (GHG) emissions in South Asian countries based on their initial national communications in Gg change is portrayed as competing with human and economic developmental needs of the world's poor. Third, climate change is a distant problem with uncertainties in its effects and is less urgent than current poverty. Consequently, many nations, particularly developing countries, are pursuing socioeconomic development paths that the industrialized nations have taken in the name of poverty alleviation, thereby compounding global warming. The success of effectively responding to the calls of global warming will need an overhaul in the way that the majority of governments and people perceive climate change. There needs to be acknowledgement that millions of people, particularly the rural poor, are losing their land, property and, sometimes, lives to the natural calamities resulting from climate change. Governments require objective thinkers regarding the result of long-term studies that confirm direct connections between GHG emissions, global warming and impacts. South Asia's efforts to respond to climate change impacts through policy formulations and the large number of projects aimed at adaptation and mitigation are a manifestation of their appreciation of the challenges from climate change. However, their abilities to respond to the impacts of climate change are highly constrained by economic resources, technological factors, access to information and skills, infrastructure, institutions and weak translation of policy into action. Real progress, if it is to be achieved, demands additional technological and financial support from industrialized nations.

3.2.1 Policy. As a response to increasing threats and risks from impacts of climate change, South Asian nations have developed several major policies and plans that directly or indirectly address climate issues (Table IV). Aside from the national communications to UNFCC and NAPA, Bangladesh (Government of Bangladesh, 2009) and India (Government of India, 2008) have developed national-level climate action plans, while Nepal (Government of Nepal, 2011;2005) has developed a strategy for climate resilience. Indian national action plans further translate into state climate action plans. Bhutan's Agriculture Ministry has implemented a European Union-supported project called the "Global Climate Alliance" to address policy and program issues for climate change and agriculture. The national developmental plans (mostly 5-year plans) are now mainstreaming climate-sensitive programs and projects derived from the existing climate plans and strategies. Large numbers of policies, acts and regulations have also been revised to become climate sensitive. Realizing that funding is a pre-requisite to the successful implementation of these policies and projects, some nations have strategized funding mechanisms. One pioneering example is from Bangladesh where they have created a Climate Trust Fund (CTF) for channeling international funds. They have also created a sister endowment called the Bangladesh

Country	National climate action plans	National focal agency	Funding mechanism
Bangladesh	NAPA (2005) Bangladesh Climate Change Strategy and Action Plan (2009)	Climate Change Unit, Ministry of Environment and Forests	Climate Change Trust Fund Bangladesh Climate Resilience Fund
Bhutan	NAPA (2006, 2012)	Climate Change Unit, NEC	None
Nepal	NAPA (2010) LAPA (2011) Strategic Program for Climate Resilience	Climate Change Management Division, Ministry of Environment	None
India	National Action Plan for Climate Change INDCs (2015)	Climate Change Division, Ministry of Environment and Forests	None

Table IV. National climate action plans, coordinating institutions and funding mechanisms

Climate Change Resilience Fund (BCCRF) for pooling national funds for financing climate-related projects. BCCRF is supported by the Government of Bangladesh, while CTF depends on donor contributions. This is a unique and successful arrangement.

3.2.2 Adaptation and agriculture. Adaptation is an adjustment in natural and human systems that occurs in response to actual (autonomous adaptation) or expected climate changes or their effects (anticipated adaptation) or planned activities supported by policy decisions (planned adaptation). Adaptation to climate changes is expected to reduce the degree of sensitivity, exposure and danger through adaptive measures. In agriculture, it is addressed through policies and programs aimed at improving productivity by using interventions such as optimizing water usage, improved varieties of crops and livestock (Venkateswarlu and Shanker, 2009).

At a broad level, adaptations in agriculture are aimed at adopting crop improvement, drought proofing and better farming practices to avert possible impacts of climate change, curving the forces leading to global warming and building capacities to deal with emerging issues. Current adaptation programs seek to minimize the adverse effects of drought on the production of crops and livestock as well as on the productivity of land, water and human resources. A major initiative towards this effort is the Indian National Initiative on Climate Resilient Agriculture (NICRA) launched in February 2011 by the hon'ble Union Agricultural Minister. NICRA outlines research strategies to be undertaken by the Indian Council of Agriculture Research and its collaborators. It further draws actions in areas of food security and livelihood through investigation of location-specific technologies and adequate infrastructures facilities such as input, output, marketing and extension education.

Successes of adaptation programs are influenced by a variety of factors, including socioeconomics, locational aspects, infrastructure, institutions and politics. Adaptation programs are mostly based on the following four conceptual building blocks of climate change resilience development with respect to food security:

(1) reducing sensitivity;
(2) reducing exposure;
(3) enhancing community-based capacity for adaptation; and
(4) institutional capacity.

These would lead to the development of climate change and disaster resilience through technology development; preparedness and awareness strengthening; and livelihoods protection and development. In general, adaptation strategies include social networks for support in times of climate stresses, common resource management, diversified income sources and traditional innovations such as ploughing early morning before dew or fog has evaporated (Kelkar and Bhadwal, 2007; Ullah and Rahman, 2014). Specific adaptation activities relating to agriculture are summarized in Table V.

3.2.3 Mitigation and agriculture. Addressing climate change must focus on agriculture as it contributes an estimated 10-12 per cent of anthropogenic GHG emissions globally or 5.1-6.1 Gt CO_2 eq/year (Smith *et al.*, 2008). This figure jumps to 17-32 per cent of emissions if related land use change and land degradation are considered (IPCC, 2007), making agriculture a larger contributor to climate change than the energy or transport sectors. The South Asian nations of Bangladesh, Bhutan, Nepal and India together emitted a total of 86,584,5.63 Gt of CO_2, 20,241.55 Gt of CH_4 and 225.51 Gt of N_2O from agricultural sectors (Government of Bangladesh, 2015; Government of Bhutan, 2012; Government of India, 2015; Government of Nepal, 2011). Furthermore, the emissions from agriculture are expected to

Sector	Adaptation options
Agriculture	Promote water use efficiency in agriculture through effective water storage (soil conservation and water harvesting) and optimization of water use (drip, micro jet and sprinkler irrigation as well as community-based resource management groups)
	Adjust agricultural production systems to production environment (short, early-maturing crops, short-duration, resistant and tolerant varieties, appropriate sowing and planting dates and proactive management)
	Improve land cultivation management
	Adopt agro-ecosystems approach to planning and production methods
	Provide weather and seasonal forecasting for climatic conditions, crop monitoring and early warning systems
	Adjust cropping calendar and crop rotation to deal with climatic variability and extremes
	Improve nitrogen use efficiency through more efficient application methods and adjustment of application rates based on precise estimation of crop needs (e.g. precision farming). The natural sources of nitrogen from organic compost will be more sustaining and would improve the soil health and crop production. Use of biological source of N will be an added advantage
	Supplementary food: Considering dwindling of cultivable land, provisions for growing and utilizing alternative/supplementary non-cereals and other food crops, particularly on non-rice land. Use of Cassava, maize, millets, potato, sweet potato; pigeon pea, "fallon" and other minor pulses for; mustard oil/groundnut/sesame/oil palm instead of imported soybean oil; local fruits instead of imported ones, etc., would have enormous security for carbohydrate, protein and fat in the future under changed climatic conditions
	Crop production on raised/floating nursery/dapog seed bed, planting of separated tillers, double transplantation:
	Develop indigenous storage facilities to increase security of food, particularly during adverse conditions
Water resources	Artificial management of flows from glacial lakes through strengthening lake outlets and controlling flow to avoid GLOFS
	Use of low-carbon technologies (such as drip irrigation, micro-jets and sprinkler) to optimize water use efficiency
	Build irrigation systems and reservoirs and manage the operation of water resources
	Advocate water use efficiency through rainwater harvesting and modern water conservation methods
	Construct cyclone polders and river protection

Table V. Summary of adaptation options for agriculture in South Asia

increase in the future because of increasing population, income, agricultural intensification and diet preferences for meat and dairy. However, agricultural practices if actively managed hold possibilities for mitigation. Potential for agricultural mitigation has been well summarized by the IPCC (2007). Such a measure is expected to reduce emissions by 1.5 to 4.3 Gt CO_2 eq/year by 2030 at future carbon prices of US$20-100 (Smith *et al.*, 2008). This reduction is contingent on meeting the following specific challenges:

- agricultural mitigation needs to be compatible with food security and livelihoods to be attractive to farmers and national governments worldwide;
- measuring and accounting of how practices affect changes in GHG emission must be cost effective; and
- reaching large numbers of farmers, policy formulations and practices at large scales are needed to achieve global emission reductions.

Agricultural opportunities for mitigating GHGs in agriculture according to Smith *et al.* (2008) falls into three broad categories:

(1) *Avoiding emissions*: Agriculture is a significant source of CO_2, CH_4 and N_2O (Paustian *et al.*, 2004), but it also presents opportunities for managing carbon and nitrogen flow if proactive interventions are built into agricultural systems. For instance, use of slow-releasing N fertilizer can reduce the emission of N_2O (Government of Bangladesh, 2011), and improved feeds can suppress CH_4 emissions.

(2) *Increasing removals*: GHGs can be removed from the atmosphere through carbon sequestration. An improved agricultural system can withdraw C from the atmosphere and store it in soil organic matter. Agroforestry systems, particularly in wastelands, for instance, can serve as repositories of C, while agricultural lands can absorb CH_4 from the atmosphere by oxidation as well as by reduced soil erosion and improved water quality.

(3) *Avoiding emissions*: Emission of GHGs can be avoided by an efficient use of residues from agricultural lands. These wastes can be converted to fuels such as ethanol or diesel (Schneider and McCarl, 2003). Although CO_2 is released upon the combustion of feedstocks, it has a net benefit when compared to fossil-derived emission.

While South Asian nations are not required to implement interventions to mitigate GHGs, they have taken initiatives to reduce GHGs by advocating energy efficiency, stringent requirements for environmental impact assessment and now, low carbon priorities. India, the world's fourth largest emitter of GHGs, committed to voluntarily cutting its emissions by 20 to 35 per cent by 2030 as compared to the 2005 levels. In 2009, Bhutan declared in Copenhagen to remain carbon neutral. Similarly, Bangladesh and Nepal made pledges to reduce emissions wherever possible. The strategies to reduce GHG emissions include low-carbon agriculture, green energy and energy efficiency, afforestation, reduced deforestation, and strong monitoring and evaluation. In the agricultural sector, focus is on cropland management, livestock improvement and soil management. In particular, the following initiatives have been adopted in South Asia to mitigate GHGs:

(1) development of energy policies that encourage raising efficiency in production and consumption of energy along with development of renewable energy sectors, particularly solar homes and biogas;

(2) implementation of CDM projects that expand the number of projects and enter into carbon trading;

(3) phasing out two-stroke engines with four-stroke engines and conversion of petrol cars into CNG fueled cars (particularly in India and Bangladesh) along with stringent emissions standard requirements for vehicles to ply on road;

(4) one major mitigation project is REDD and REDD+; for instance, in Bangladesh, the collaborative REDD and improved forest management Sundarbans project (CRISP) is geared towards reducing emissions and enhancing livelihoods and exploring carbon-financing opportunities;

(5) introduction of labeling programs for appliances and promotion of energy-saving devices;

(6) energy and building codes that are expected to reduce electricity consumption by 30-40 per cent;

(7) fuel switching to green sources. A significant initiative in this area has been passing the US$1 levy on domestic and imported coal and the promotion of renewable energy sources such as solar in India;

(8) in the agricultural sector, the major mitigation strategies that emerged are:

- Improving rice management: Cultivated wetland rice soils emit significant quantities of methane. Draining the wetland rice periodically can reduce emissions during the growing season. During the off-rice season, improved water and irrigation management can reduce methane emissions, particularly by growing dry land crops.
- Nutrient management through the use of controlled fertilizers based on the needs of the crops and improved farming (low tillage, alternate wetting and drying, and SRI) and waste management practices to reduce emission from agriculture through cost-effective, slow-releasing super-granule N fertilizer and development of applicators for fertilizers.
- Evaluate carbon sequestration potential of different land use systems, including opportunities offered by conservation agriculture and agro-forestry.
- Identify cost-effective opportunities for reducing methane generation and emission in ruminants by modification of livestock diet, and in rice paddies, by water and nutrient management. Renew focus on nitrogen fertilizer use efficiency with the added dimension of nitrous oxide mitigation.

3.3 Gaps and needs

3.3.1 Capacity and training needs. Currently, the institutional and technical capacities within the government, NGO and private sectors in South Asia are very poor. Capacity building of officers at all levels from governments, business and the private sectors to carry out research and assessment, monitoring, extension and training, and policy change are critical for efficiently addressing climate issues. South Asian countries have to invest in meteorological data collection and analysis to provide their citizens and climate sectors with reliable information. This calls for an increased number of weather stations equipped with state-of-the-art technology to forecast weather patterns. Capacity building must focus on upgrading current capacity and exposing the current experts to increase their competency; strengthening data collection and creating reliable and robust databases; upgrading the existing remote sensing and modeling technologies with state-of-the-art technology; improving the understanding of regional and local dimensions of vulnerability; and raising public awareness and building capacity at all levels of the society.

3.3.2 Knowledge gaps and potential research areas. Many reports including the IPCC reports tend to converge on the fact that the South Asian region lacks consistent long-term data and call for global, regional and national attention to fill the gap. There is a need to increase budget allocation, improve research facilities and equip researchers with the technical know-how to address issues of food security and climate change. Current gaps include lack of knowledge, scientific data and information related to the science of climate change and its impact on different geographical and socioeconomic development sectors and use of climate modeling to assess the likely impacts, inadequate water-saving technology for rice cultivation, and lack of basic knowledge on the relationship between climate variation and health and nutrition effects. High-quality robust research is needed to identify potential technologies and guide policy decisions to better adapt to climate change in South Asian agriculture. Future research needs to:

- understand farmer's understanding of climate change projections and potential adaptation pathways;

- assess agricultural vulnerabilities and map potential high-risk areas to help policy makers and researchers better understand and prepare for the likely impacts of climate change in the region;
- assess current farming practices and how these are likely to change in the coming years to help identify appropriate technologies and practices to improve resilience of agricultural communities in the region;
- inventory, understand and identify local adaptation strategies that can be effectively scaled up;
- develop and test different varieties of crops that are resistant to climate stress, such as drought, salinity and extreme heat; and
- explore and implement adaptation strategies that are low carbon.

3.3.3 Policy and governance. Lack of attention to develop a capable organizational structure with the necessary financial and human resources for addressing climate and food security is a significant barrier in South Asia. There is an absence of an enabling environment for technical and financial opportunities at the national and international levels for the process of addressing climate change impacts. In addition, there is a lack of regional cooperation to address the adverse impacts of climate change between upstream and downstream areas to promote regional cooperation.

A long-term climate-resilient strategy for South Asia is critical to overcome this lack of financial and political support. This strategy must also spell out steps to bridge the existing gap between policy and implementation. Governance must be improved through decentralization and accountability to translate policy into action. One recurring inconsistency is the gap between excellent policy documents at central government levels with poor implementation at state and local government levels. Civil societies and farmer groups must be fully on board and play a key role in increasing efficiency in this translation.

4. Conclusion

While climate change is a global problem requiring a global solution, South Asia is highly sensitive to climate change and must act quickly to both adapt to and mitigate climate-related impacts, if it is to achieve progressive economic development. The South Asian nations of Bangladesh, Bhutan, Nepal and India are equally susceptible to the impacts of climate change. While glacier melts leading to GLOFs can devastate fertile river valleys in the mountains, the sea level rise can submerge large coastal areas of Bangladesh and India. South Asia has shown consistent trends in overall warming over the past 100 years. Studies in Nepal and China have shown that temperatures are rising at higher rates in high-altitude areas than in the others areas (ICIMOD, 2010). This has resulted in decreasing the areas covered by permafrost and glaciers, with many of the Himalayan glaciers receding at a rate faster than the world average. In many areas of South Asia, a greater proportion of total precipitation appears to be falling as rain, resulting in earlier snowmelts and short winters. These changes not only are the cause of natural hazards but also affect river regimes and ecosystem services, including water supply and livelihoods. There is an urgent need to conduct research to reduce impacts and help develop climate-resilient strategies.

Unless strategic adaptation and mitigation efforts are written into national developmental programs and backed by both funding and policy, the progress of economic development in South Asia will be significantly slowed down by the impacts of climate change. The views on who should take leadership in addressing climate issues are as diverse as South Asian culture. There is a general perception among government officers, communities and the others that global warming is a responsibility of the rich industrialized countries as they are the culprits for emitting GHGs. In the face of weak political leadership, these perceptions can prove to be counterproductive and render the South Asian population, particularly vulnerable groups such as women, children and the poor, to the impacts of climate change.

However, there exists hope among a small group of people mostly in the civil society and private sectors, who believe that addressing climate change is a global problem requiring local solutions and that each country irrespective of whether it is guilty of contributing to global warming should be proactive and do whatever possible to help address climate issues. These individuals and institutions must be given the respect and political support to become ambassadors of climate change programs in South Asia. Such initiatives when combined with pro-climate government support will present excellent opportunities for advocacy and information sharing in raising public awareness about the inevitability of the need to address climate to achieve human development goals. Efforts must then be expended to collectively channel funds to build institutional, professional capacity and technological knowledge to reinforce South Asia's efforts to suppress the barriers presented by climate change towards its socioeconomic development agenda. National governments must ensure an enabling environment and legal backing to translate policies, programs and projects into actions at the grassroots level. Only then will South Asia start to make a mark in its arduous battle against climate change.

References

Banerjee, O., Mahzab, M., Rihan, S. and Islam, N. (2015), "Economy-wide analysis of climate change impacts on agriculture and food security in Bangladesh", *Climate Change Economics*, Vol. 6 No. 1.

FAO (2010), "Climate-smart", *Agriculture – Policies, Practices and Financing for Food Security, Adaptation, and Mitigation*, Rome.

Government of Bangladesh (2009), *Bangladesh Climate Change Strategy and Action Plan*, Ministry of Environment and Forests (MOEF), Government of Bangladesh, Dhaka.

Government of Bangladesh (2011), *Bangladesh Country Investment Plan: A Road Map Towards Investment in Agriculture, Food Security, and Nutrition*, Food Planning and Monitoring Unit (FPMU), Ministry of Food and Disaster Management, Dhaka.

Government of Bangladesh (2015), *Intended Nationally Determined Contributions (INDC)*, Ministry of Environment and Forests (MOEF), Government of Bangladesh, Dhaka.

Government of India (2004), *India's Initial National Communication to the UNFCC*, Ministry of Environment and Forests, New Delhi.

Government of India (2008), *National Action Plan on Climate Change*, Prime Minister's Council on Climate Change, Government of India, New Delhi.

Government of India (2015), *India's Intended Internationally Determined Contribution: Working Towards Climate Justice*, Ministry of Environment and Forests, Government of India, New Delhi.

Government of Nepal (2004), *First National Communication to UNFCC*, Ministry of Environment, Government of Nepal, Kathmandu.

Government of Nepal (2005), *National Adaptation Plan of Action*, Ministry of Environment, Government of Nepal, Kathmandu.

Government of Nepal (2011), *Strategic Program for Climate Resilience*, Ministry of Environment, Government of Nepal, Kathmandu.

Government of Nepal (2016), *Intended Nationally Determined Contributions (INDC)*, Ministry of Population and Environment (MOPE), Government of Nepal, Kathmandu.

ICIMOD (2010), *Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas*, ICIMOD, Kathmandu.

IEA (2007), *CO2 Emissions from Fossil Fuel Combustion 1971-2005*, IEA, Paris.

IPCC (2001), *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, MA.

IPCC (2007), *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability*, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, MA.

Islam, M.A., Shitangsu, K.P. and Hassan, M.D.Z. (2015), "Agricultural vulnerability in Bangladesh to climate change induced sea level rise and options for adaptation: a study of a coastal Upazila", *Journal of Agriculture and Environment for International Development*, Vol. 109 No. 1, pp. 19-39.

Jandl, R., Borsdorf, A., van Miegroet, H., Lackner, R. and Psenner, R. (Eds) (2009), *Global Change and Sustainable Development in Mountain Regions*, Innsbruck University Press, Innsbruck.

Kelkar, U. and Bhadwal, S. (2007), "South Asian regional study on climate change impacts and adaptation: implications for human development", *Human Development Report, Occasional Papers*, UNDP.

Kumar, K.S. and Parikh, J. (2001), "Socio-economic impacts of climate change on Indian agriculture", *International Review of Environmental Strategies*, Vol. 2 No. 2, pp. 277-293.

Mainuddin, K., Rahman, A., Islam, N. and Quasem, S. (2011), *Planning and Costing Agriculture's Adaptation to Climate Change in the Salinity-Prone Cropping System of Bangladesh*, International Institute for Environment and Development (IIED), London.

Morton, K. (2011), "Climate change and security at the third pole", *Survival*, Vol. 53 No. 1, pp. 121-132.

NEC (2006), *Bhutan National Adaptation Programme of Action to Climate Change*, National Environment Commission (NEC), Royal Government of Bhutan, Thimphu.

Opu, K.R., Masum, A.A., Bisawas, R. and Islam, S. (2014), "Flood frequency analysis by probability and stochastic method for Padma river, Bangladesh", *American Journal of Civil Engineering*, Vol. 2 No. 1, pp. 8-11.

Ortiz, R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, D., Dixon, M., Ivan Ortiz-Monasterio, J. and Reynolds, M. (2008), "Climate change: can wheat beat the heat?", *Agriculture, Ecosystems and Environment*, Vol. 126, pp. 46-58.

Pathak, H., Ladha, J.K., Aggarwal, P.K., Peng, S., Das, S., Singh, Y., Sing, B.K.S.K., Mishra, B., Sastri, A.S.R.A.A., Aggarwal, H.P., Das, D.K. and Gupta, R.K. (2003), "Trends of climate potential and on-farm yields of rice and wheat in the Indo-Gangetic plain", *Field Crops Research*, Vol. 80, pp. 223-234.

Paul, B. and Rashid, H. (1993), "Flood damage to rice in Bangladesh", *The Geographical Review*, Vol. 83 No. 2, pp. 151-159.

Paustian, K., (2004), "Agricultural mitigation of greenhouse gases: science and policy options", *Council of Agricultural Science and Technology (CAST) Report*, R141 2004, ISBN 1-887383-26-3.

Rastogi, N.P. (2011), "Winds of change: India's emerging climate strategy", *The International Spectator*, Vol. 46 No. 2, pp. 127-141.

Ravindran, S. (2014), "Mumbai will likely flood again-and nobody's doing much about it", *The Guardian*, Mumbai, available at: www.theguardian.com/cities/2014/nov/27/mumbai-flood-rain-monsoon-city-planning

Schild, A. (2008), "The case of Hindu Kush-Himalayas: ICIMOD's position on climate change and mountain systems", *Mountain Research and Development*, Vol. 28, pp. 328-331.

Schneider, U.A. and McCarl, B.A. (2003), "Economic potential of biomass based fuels for greenhouse gas emission mitigation", *Environmental & Resource Economics*, Vol. 24, pp. 291-312.

Singh, J.S., Pandey, U. and Tiwari, A.K. (1984), "Man and forests: a central Himalayan case study", *Ambio*, Vol. 13, pp. 80-87.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008), "Greenhouse gas mitigation in agriculture", *Philosophical Transactions of the Royal Society B*, Vol. 363 No. 1492, pp. 789-813.

TERI (2010), "Climate change mitigation measures in India", International Brief 2, TERI, New Delhi.

Timsina, J., Jat, M.L. and Majumdar, K. (2010), "Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management", *Plant and Soil*, Vol. 335, pp. 65-82.

Tiwari, P.C. and Joshi, B. (2014), "Environmental changes and their impact on rural water, food, livelihood, and health security in Kumaon Himalayas", *Journal of Urban and Regional Studies on Contemporary India*, Vol. 1 No. 1, pp. 1-12.

Ullah, M.B. and Rahman, M.H. (2014), "Assessing vulnerability and adaptation to climate change by farming communities in southwestern coastal Bangladesh", *Journal of Environmental Science and Natural Resources*, Vol. 7 No. 2, pp. 31-35.

UNEP (2003), *GEO Year Book 2003*, United Nations Environmental Program (UNEP), Nairobi.

UNEP (2007), *GEO Year Book 2007*, United Nations Environmental Program (UNEP), Nairobi.

Uphoff, N. (2006), "The system of rice intensification (SRI) as a methodology for reducing water requirements in irrigated rice production", *International Dialogue on Rice and Water: Exploring Options for Food Security and Sustainable Environments*, IRRI, Los Banos, pp. 1-23.

Venkateswarlu, H. and Shanker, A.K. (2009), "Climate change and agriculture: adaptation and mitigation strategies", *Indian Journal of Agronomy*, Vol. 54, pp. 226-230.

World Bank (2010), *Final Report: India: Andhra Pradesh Drought Adaptation Initiative– Lessons from Community Based Adaptation Approaches to Strengthen Climate Resiliencies*, World Bank India, New Delhi.

Further reading

Royal Government of Bhutan (2012), *Second National Communication*, National Environment Commission (NEC), Royal Government of Bhutan, Thimphu.

About the authors

Sonam Wangyel Wang is a socio-environmental Scientist with special interest in understanding the fundamentals of the human-environment interface and the impact of climate change on this relationship. Dr Wang is currently pursuing PhD in Natural Resource Policy and is a MS in Natural Resource Policy and Management at Cornell University. In addition, he holds a master's degree in public administration from Harvard University and BSc (hons) in Forestry from University of Wales, Bangor, UK. In the past, he has worked as the Chief of Bhutan's National Park Service, the Director of Bhutan Royal Education Council and a Research Associate at Montana University, USA, and the Smithsonian Institute, Washington D.C., USA. He has also worked as a Consultant to governments, NGOs, and international agencies on issues ranging from climate change adaptation, poverty, gender and biodiversity to project development.

Woo-Kyun Lee works at Korea University's Division of Environmental Science and is also Director of BK21+ Eco Leader in Education Center and Director of Environmental GIS/RS Center. His research focuses on climate change adaptation in mid-latitudes, forest management, GIS and RS. He earned his PhD from College of Forestry, Gottingen University, Germany, and his MS and BS in Forestry from Korea University, Seoul, South Korea. He holds numerous affiliations both nationally and internationally including as an advisor for an international cooperation project between IIASA and National Research Foundation of Korea. Woo-Kyun Lee is the corresponding author and can be contacted at: leewk@korea.ac.kr

Yowhan Son is a highly distinguished professor working internationally and nationally. Professor Son earned his PhD from University of Wisconsin-Madison, USA, and has a master's degree from both Colorado State University, USA, and Korea University, South Korea. He is the current Director of the Global Carbon Project – Korea Office and has worked as Policy Advisor to the Korean Government in the past. His research focuses on forest management, forest carbon modeling and forest soils in Korea and abroad.